Manganese Reserves and Resources of the World and Their Industrial Implications

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U.S. manganese needs are 98% imported. Land-based manganese reserves and resources of 56 countries are discussed in terms of gross quality and quantity. Accessibility and availability of the resources, changing grades of ore and the production capability of these countries to produce for the remainder of this century are considered. Ore mining, beneficiation, metallurgical processing and smelting technology are reviewed. The industrial implications of this dependence is assessed. Seabed manganese nodules are considered as a possible future resource, but are not included with the worldwide estimates.

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Report of

The Panel on Manganese Supply and
Its Industrial Implications

of the

Committee on Technical Aspects of
Critical and Strategic Materials

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The report has been reviewed by a group other than the authors according to procedures approved by a Report review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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DEDICATION

The NMAB Panel on Manganese Supply and Its Industrial Implications dedicates its report to a fellow member well-known and highly respected in the scientific community. Dr. S. Frederick Ravitz (Fred to most people) spent nearly fifty years in the fields of physical chemistry and extractive metallurgy. He was always active in various professional activities and in 1975 he chaired the National Materials Advisory Board Committee on Manganese Recovery Technology. His distinguished career did not end with his retirement as Professor of Metallurgy at the University of California at Berkeley, as he was invited to become a member of this panel. The contributions and guidance Fred gave to the panel, especially in the sections of the report covering mining and metallurgy, helped to give proper perspective in many critical technical areas. In the'latter stages of the report preparation, everyone missed his gentle manner and helpful suggestions. The panel regrets his passing and that he cannot see the end product of his and his colleagues' efforts.

ABSTRACT

Manganese is a critical raw material for the steel industry, and the industry in turn is one of the basic institutions upon which a substantial portion of the U.S. economy depends. National demand for manganese in all forms now ranges from 1 to 1.4 million metric tons (m.t.) annually, of which 98 percent is imported. Because of the importance to the United States of manganese imports, it is clearly in the national interest to have available the best possible estimate of manganese resources worldwide.

This report discusses the geological occurrences and assesses the manganese reserves and resources of 56 countries in terms of gross quality and quantity of the element. Accessibility and availability of the resources, changing grades of ores, and the capability of the countries to continue to produce ore at current or increased levels for the remainder of this century are considered. Major and minor sources are identified and evaluated. Seabed manganese nodules are considered as a possible future resource but they are not included with the worldwide estimates. This approach is in accordance with guidelines provided by the sponsoring agency.

Manganese ore mining, beneficiation, metallurgical processing and smelting technology are reviewed and assessed in terms of their impact on current and future manganese supplies and raw materials costs. The heavy dependence of the noncommunist world for its manganese supply on a limited number of freeworld manganese producers also is discussed. The industrial implications of this dependence and factors or actions that might result in cost increases, or the curtailment or disruption of ore and ferromanganese supplies are assessed.

PREFACE

Data on reserves and resources of minerals are numerous (Figure 1), but often incomplete and inconsistent. Because of deficiencies in the data, interpretation and analysis by different individuals often give differing results. This situation is particularly acute for manganese minerals because of geological and geographical factors and because of differences in mining techniques, recovery processes, and political-economic situations that often are unique to a particular mineral community where it is mined.

The panel was convened to prepare an independent evaluation of the information available about world sources of manganese. In its compilation of data, the panel endeavored to adhere closely to the definitions and rules for classification of reserves and resources as described in U.S. Geological Survey Bulletin 1450A (1976). Consideration was given not only to data appearing in various published "reliable sources," but also to the generation of new data provided by personal and special contributors to the panel.

Because of inconsistencies and incompleteness in the data and because of lack of uniformity of classification systems used in different countries, judgments often had to be made by the panel. The results involved an independent effort and represent the best estimates of the panel based on data and information available through February 1981.

PART I. MANGANESE SUPPLY AND APPLICATIONS summarizes the results of the study. PART II. DESCRIPTION OF WORLD OCCURRENCES provides additional detail on major and minor sources of manganese worldwide.

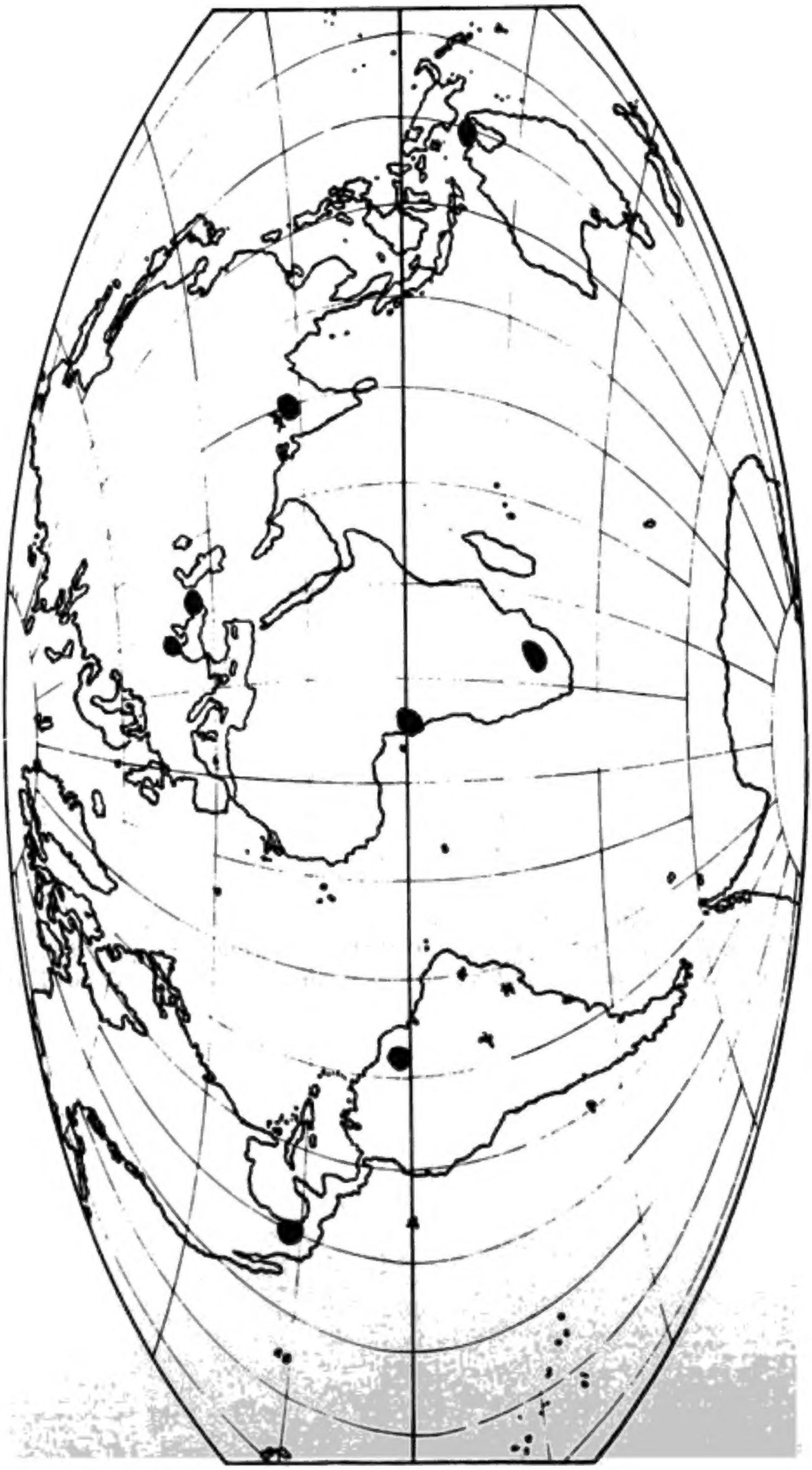

FIGURE 1. Major World Sources of Manganese Ores

ACKNOWLEDGMENTS

The Panel on Manganese Supply and its Industrial Implications wishes to acknowledge numerous sources of background information and detailed supply data. Guest contributors participated in discussions with the panel at two separate meetings. At one meeting Dr. Jagdish C. Agarwal (formerly of Kennecott), Vice President, Charles River Associates Incorporated covered the status of seabed nodules mining and processing technology; Dr. John F. Elliott, Director of the MIT Mining and Minerals Resources Research Institute discussed manganese in steelmaking; and Mr. Franz R. Dykstra supplied a detailed critical evaluation of USSR manganese reserves and resources.

On another occasion, Mr. Atsuo Akiyama of the Mitsubishi Corporation journeyed from Japan to discuss Japanese industry use of manganese in steelmaking; and Mr. W. A. Preston, British Steel Corporation, came from England to review his evaluation of various manganese reserves and resources of major producing countries. Although they were unable to personally present their views, the following specialists sent important data to the panel for their consideration and use:

Dr. P. L. Dancoisne, Manganese Centre, Neuilly-sur-Seine, France
Dr. Dieter G. Kamphausen, German Institute of Economic Research, Berlin, Federal Republic of Germany
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Additional personal presentations before the panel were made by Mr. George Borden, Union Carbide Corporation on ferromanganese production, and Dr. Richard F. Horsnail, AMAX Explorations Incorporated, presented a review of China's reported manganese deposits.

The panel was also privileged to have outside teams of contributors prepare written reviews on reserves of various potential or current producer countries; their efforts are gratefully acknowledged:

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Special thanks go to the various liaison representatives who generously supplied certain background data that helped make the panel report more complete. In addition, the U.S. Central Intelligence Agency library provided the maps used in the report to locate the identified reserves and resources in each country.

Miss Mary Margaret Franclemont is given acknowledgment for her effective editing of the report, and particular thanks go to Charles River Associates, Incorporated, her employer, for permitting Miss Franclemont to undertake this task.

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PART I

MANGANESE SUPPLY AND INDUSTRIAL IMPLICATIONS

CHAPTER ONE

SUMMARY

Manganese is a critical raw material for the iron and steel industry which accounts for almost 90% of the demand. National consumption of the metal in all forms now ranges from 1 to 1.4 million m.t. per year of contained Mn of which about 98% is imported, and U.S. demand for manganese is expected to increase by about 1.6% annually through the year 2000. The nearly complete dependence of the United States on imports is expected to continue as the cost of producing market-grade manganese products from low-grade domestic resources probably will not be economically competitive with the price of high-grade imported ores or products. Because of that dependence, developments in the world manganese market can have serious implications for the United States. Depletion of low-cost, high-grade deposits, technological innovations, jumps in demands, shortfalls in investment for capacity expansion, interruptions in supply due to political turmoil in producing countries, and manipulation of the market by dominant producers all could have far-reaching effects on the U.S. economy.

The Bureau of Mines (BOM), United States Department of the Interior, is the principal government agency concerned with collecting and analyzing data relating to worldwide manganese ore reserves and supplies, and projecting future demands for the element. In assessing the reserves and resources, data are collected from diverse domestic and foreign governmental sources, business, individuals, mineral trade journals, and by survey forms. Manganese reserve and resources information from some countries is easily interpreted. That obtained from others is difficult to assess because the classification systems for distinguishing between ore reserves and resources differ throughout the world even when purportedly following a specific classification system. Furthermore, much of the data available to the Bureau of Mines does not consider recovery and accessibility factors, or the type or character of the ore other than its manganese content. The terms recovery and accessibility are semi-quantitative qualifiers and are defined as follows: accessibility--this factor takes into consideration two elements. One is the economic and physical factors such as deposit locations, terrain, and transportation facilities which favor or limit access of men and equipment; and movement of ore to world markets. The other element is the geopolitical climate which may or may not favor production of ore from a resource in a given country or location; recovery--application of this factor gives a reserve figure in terms of shipping product, or in terms of quantity of ore that can be removed from the deposits if mining and processing recoveries and losses are considered. Mining losses can include ore left behind as underground support pillars, losses due to dilution with waste rock, material too thin to be recoverable by the technique used, etc. Thus, BOM reserve estimates may differ from evaluations which are made on the basis of identifiable near-term economically mineable manganese ores and products derived therefrom. World manganese resources estimates also vary but these, at present, are not of concern because of their magnitude.

In estimating world-wide manganese reserves and resources, the panel used the definitions in U.S. Geological Survey Bulletin 1450-A (1976) entitled, Principles of the Mineral Resource Classification System of the U.S. Bureau of Mines (BOM) and U.S. Geological Survey (USGS). As defined in the Bulletin, reserves are "That portion of the identified resource from which a useable mineral and energy commodity can be economically and legally extracted at the time of determination. The term 'ore' is used for reserves of some minerals." Based on this classification the panel found that there is no shortage of manganese worldwide, and that there is adequate manganese reserve in situ to meet free-world and centrally planned economy countries' needs throughout this century.

The principal free-world sources of manganese are the Republic of South Africa, Gabon, India, Australia, and Brazil. Mexico could become a significant supplier in the future but India's role as a major supplier appears to be on the wane. With an expected increase in world manganese demand from about 8.7 million m.t. (manganese content) in 1977 to 19.4 million m.t. by the year 2000, production will have to be expanded, principally from the current major source countries. However, even though manganese reserves "in situ" are adequate, from an accessibility and availability standpoint there is no guarantee that free-world supplies will keep pace with demand unless the major producers are able to expand their physical facilities for mining, processing, and transporting the ores and processed materials.

The USSR is a major manganese producer and probably will continue to satisfy its own manganese needs for the next 30 years by using submarginal resources as measured by free-world standards. Manganese ore exports by the Soviets to Central Economy Countries have been declining and centrally planned economy countries' purchases of high-grade manganese ore from the free-world producers have increased in the last decade. Purchases can be expected to increase even more during the rest of this century, thereby increasing the competition for free-world supplies.

The availability of high grade ores (+45% Mn) used to blend with lower grade materials for ferromanganese manufacture is declining and the possibility is that lower grade ores will be used to make the alloy in the future. The technology for producing standard, medium- and low-carbon ferromanganese from lower grade feeds is available but the costs involved in smelting the lower grade materials will be higher. Standard ferromanganese production capacity in the United States in the last two decades has decreased significantly, whereas countries possessing major reserves of ore are increasing production capacity. In all probability, the manganese importing nations will maintain residual production capacity but additional new production facilities will be located close to the sources of ore.

Manganese ore mining, beneficiation, and processing technology used throughout the world is relatively simple and straightforward. Underground mining in the major producing countries is expected to increase, and this will be at substantially greater cost and poorer mining extraction than is the case with pit mining because of the ore left behind for roof support. Also, ore grades will be lower. As ore grades decline, beneficiation will be applied more widely to recover marketable products. In addition, pyrometallurgical processes such as pelletizing, nodulizing, and sintering probably will receive more attention for agglomerating oxide ore fines and upgrading manganese carbonate ores. Other than these relatively simple upgrading approaches, the outlook for application of more sophisticated methods for beneficiating the low-grade ores is unlikely in the foreseeable future.

The deep-sea nodules of the North Pacific Ocean are a potential manganese resource. Development of systems for mining and processing the nodules for their manganese, copper, nickel and cobalt content has been under investigation since the mid 1960s, but the introduction of commercial operations as an alternative to U.S. import dependence appears to be at least 10 years away. Before commercial operations are undertaken, mining systems will have to be perfected and installed. Recent U.S. legislation encourages commercial activity in this field.

The dependence of the non-communist nations on five free-world manganese producers during the next two decades raises questions concerning the U.S. industrial implications of this dependence. The effect of a manganese shortage regardless of the cause would be substantial. The United States is coming to depend more heavily on imports of ferromanganese as the manganese exporting nations expand ferromanganese production capacity. Adverse effects of this are the certain erosion of domestic ferromanganese furnacing capability with an attendant loss of jobs. The unit cost of the manganese in the imported ferromanganese will be higher than that of the imported ore, but whether this cost will be offset by savings in shipping costs of the alloy as compared to ore remains to be seen. The expected increased dependence of communist-bloc countries on imports from the west will place added pressure on free world reserves and resources development. This will result in more remote, lower grade, and more complex deposits being brought into production. For the past 25 years the communist and non-communist markets have been viewed in isolation from each other, but in the future they must be viewed together.

Assuring U.S. access to future manganese supplies will require a long-term plan involving complex international political and economic strategies that can neither be devised nor carried out by the U.S. steel and ferromanganese industries alone. Since similar situations are being encountered in procuring other critical materials, the development and implementation of a national minerals policy is needed that recognizes and resolves the U.S. mineral dependence problems on a systems basis rather than from a simplistic raw materials approach: the complex nature of the manganese supply, processing and use chain must be considered, including such issues as world supply and demand patterns, adequacy and stability of U.S. supply sources, transportation problems, displacement of domestic ferromanganese furnacing capacity, national stockpile reserves, and diversification and development of new sources of supply.

CHAPTER TWO

INTRODUCTION

Manganese is a critical raw material for the steel and ferrous foundry industries, which in turn are basic industries upon which a substantial portion of the U.S. economy depends. The commercial importance of manganese derives mostly from the beneficial effects it has on iron and steel, i.e., desulfurization; deoxidation; inhibition of grain-boundary carbide formation; and the alloying effects of increased strength, toughness, hardness, and hardenability. Manganese also provides similar properties to iron castings. Other uses are as alloys with aluminum, magnesium, or copper. Manganese dioxide is used as a depolarizer in dry-cell batteries, and as an oxidant in the production of a variety of chemicals. Manganese or manganese chemicals are used to impart color in ceramics and are ingredients in some paints, dyes, fungicides, and pharmaceuticals.

U.S. demand for manganese in all forms now ranges from 1 to 1.4 million m.t. annually, of which 98% is imported. Based on current and projected prices and the low quality of our domestic resources, the United States will continue to import manganese. This situation has important implications, especially in light of the fact that there are no suitable substitutes for the metal in its major application, the manufacture of iron and steel. Forecasts indicate that there will be a substantial increase in worldwide demand for manganese through the year 2000 as shown in Table 2-1 (Bureau of Mines, 1979). This could result in keen competition for available supplies, not only by the free-world nations but also by the centrally planned economy countries. Should U.S. supply of manganese be curtailed or interrupted for this or other reasons, the adverse effects on the economy would be far-reaching.

The principal free-world sources of manganese are the Republic of South Africa, Gabon, India, Australia, and Brazil. These free-world nations accounted for about 54% (Bureau of Mines, 1979) of total world production in 1977, and of the total for the five countries, the African nations provided nearly two-thirds. Therefore, in consideration of the world political climate, it is clearly in the

TABLE 2-1

FORECASTS OF U.S. AND REST-OF-WORLD MANGANESE DEMAND
1977-2000
(1000 m.t. Manganese Content)*

		2000 Forecast Range		Probable		Probable Average Annual Growth Rage(1) 1977-2000 (Percent by weight, dry basis)
	1977	Low	High	1985	2000	
United States:						
Total	1,381	1,624	2,222	1,506	1,932	1.6 (2)
Cumulative (2)	-----	34,466	40,815	11,791	37,187	---
Rest of World:						
Total	7,302	15,600	21,677	11,065	17,505	3.1
Cumulative (3)	-----	274,821	333,776	79,816	292,961	---
World:						
Total	8,684	17,233	23,945	112,607	19,410	2.9
Cumulative	-----	309,287	374,591	91,607	330,148	---

*Original figures converted from short tons to metric tons

(1) Compounded
(2) Calculated from the 20-year primary demand trend value of 1.330 million m.t. for 1977.
(3) Calculated from the 18-year primary demand trend value of 8.661 million m.t. for 1977.

SOURCE: U.S. Bureau of Mines,(1979)

national interest to provide the government and the private sector with the best possible estimate of manganese resources worldwide, including their geographic accessibility and degree of availability. Of specific concern are the resources and reserves of the free world and, in particular, of those nations regarded to be the more stable sources of manganese supply.

2.1 BUREAU OF MINES MINERAL DATA COLLECTION AND ANALYSIS SYSTEM

The Bureau of Mines (BOM) is the principal government agency concerned with collecting and analyzing data relating to worldwide manganese ore reserves and supplies, and in projecting future demands for the element. In carrying out this responsibility, the BOM relies on a variety of data sources. Periodic and special reports from Department of State mineral reporting officers and regional resource attaches in U.S. consulates and embassies, statistical and other reports of foreign governments, and contacts with other knowledgeable foreign sources are important. Information obtained from canvassing the industry and business sectors; contacts with industry, academia, the U.S. Geological Survey and other government agencies; study and analysis of the literature, trade journals, and other periodic news reports and publications provide additional major input to the BOM's data collection system and to its assessment of reserves and resources.

Easily interpreted manganese ore reserve and resource data are obtained readily for some countries, but for others, differing and often uncertain data bases that have been used make assessment difficult. Classification systems for distinguishing between ore reserves and resources differ throughout the world, even when purportedly following a specifically defined system such as that of Bulletin 1450-A (1976).

Much data available to the Bureau of Mines appear to give little recognition to recovery and accessibility factors, or to the type or character of the ore other than its manganese content. Distinctions between oxide and carbonate ore may or may not be clear.

2.2 CHARGE TO THE PANEL

This study was conducted by the Panel on Manganese Supply and Its Industrial Implications of the Committee on Technical Aspects of Critical and Strategic Materials at the request of the Bureau of Mines, U.S. Department of the Interior. The charge to the panel was to examine critically world sources of manganese with respect to quantity, quality, and, as warranted, production capabilities. The primary objective was to make the best estimate of the gross weight and manganese content of land-based reserves, and to a lesser extent, the other identified resources of each country known to possess manganese deposits of any consequence. Sea-floor deposits were acknowledged as a resource, but were not to be given detailed study.

2.3 SCOPE OF THE STUDY AND APPROACH

The organization and content of this report reflect the consensus of a multi-disciplinary panel. Individual chapters deal with the worldwide geological occurrences of manganese deposits, the status of seabed nodule development, the technology of manganese ore mining and processing, and industrial implications.

A problem faced by the panel involved the adoption of acceptable definitions for manganese resources, reserves, and the various ore classifications. Some of the questions which arose concerned the tenuous distinction between resources and economic reserves, and economic and subeconomic reserves, inasmuch as they are changing constantly due to new technology developments, price, and other factors. Furthermore, assessing the reliability of raw and converted data from a large number of diverse sources was an obstacle to accurately identifying the proper resource categories. Further discussion of these and other problems and their solutions is provided under the appropriate chapter headings. After considering a number of alternative approaches, the panel adopted the general classification system outlined in Bulletin 1450-A (1976). Also, the estimates were influenced to some considerable degree by the panel's assessments of the current or future accessibility of certain resources and the reliability of supply from the primary source nations. The panel has made every effort to be consistent in presenting all data in metric tons (m.t.); however, some deviations do exist. Conversions to commonly used weights are provided below.

Metric ton = 2205 pounds (Avdp)
= 1.102 short tons
= 0.984 long ton

Short ton = 2000 pounds (Avdp)
= 0.893 long ton
= 0.907 metric ton

Long ton = 2240 pounds (Avdp)
= 1.120 short tons
= 1.016 metric tons

REFERENCE

Bureau of Mines, U.S. Department of the Interior. Manganese--Mineral Commodity Profiles, (Update of October 1977 issue), Washington, D.C., U.S. Government Printing Office, July 1979.

CHAPTER THREE

GEOLOGICAL OCCURRENCE WORLDWIDE

3.1 MANGANESE ORE OCCURRENCES VERSUS ORE DISCOVERIES

Manganese comprises about 0.1% of the earth's crust and is the 12th most abundant element. Some common rocks contain as much as 0.16% manganese on the average. The formation of ore-grade material requires manganese to be concentrated from 250-500 times above its crustal background level. Such a concentration factor is similar to that of many other types of metallic ores. Manganese can be moved and concentrated readily in many geologic environments. These factors account for the very large number of known subeconomic manganese concentrations and suggest that many undiscovered concentrations may exist in areas where exploration is incomplete.

An economically important manganese concentration by today's standards must have a large tonnage of ore. In addition to being high enough in grade, it must also meet other requirements such as mineralogic form and contain a minimum amount of undesirable elements. Hence, only a small proportion of manganese deposits is exploitable. Nevertheless, it is expected that some important, large, undiscovered deposits may exist.

Some of the important geologic processes that concentrate manganese are restricted to zones at or very near the earth's surface. Therefore, as a general rule, there is a higher probability of finding manganese ore at the surface than at depth, but more deeply buried ores of some genetic types are also possible. In addition, many geographic regions likely to contain manganese ore have been intensely searched. In these areas, it can be judged that most, if not all, large deposits with prominent surface expression have been found. It is likely, therefore, that future discoveries, if made, either will be in new, currently unrecognized manganese-bearing regions, or will be buried deposits with little or no surface expression. This is because some older surface deposits might have been buried and preserved by geologic activity.

Several factors make such discoveries very difficult:

- Manganese ore has no distinctive geophysical expression so that geophysical techniques that are very successful in finding deposits of other metals are of little use in manganese exploration.

- Manganese is an abundant and readily concentrated element so that geochemical prospecting techniques are of little use. Manganese concentrations can be found so frequently, mostly not related to ore bodies, that the results are not sufficiently discriminating to be of value in the search for ore.

- Some manganese ores, unlike many other metallic ores, are not sufficiently unusual in appearance to attract the attention of untrained individuals and therefore are not likely to be found accidentally by a nongeologist.

- The present level of understanding of the geologic controls of manganese ore formation is inadequate to predict, on geologic grounds, sufficiently small regions of high potential to be explored effectively.

Thus, although it is likely that large undiscovered ore bodies exist, finding them is very difficult, and discoveries are unlikely unless very extensive research and subsurface exploration are carried on, or they are found by chance.

3.2 CLASSIFICATION OF MANGANESE DEPOSITS

Manganese deposits are varied both as to their geographic distribution and to their type of geologic occurrence. Geographically, they are known to occur on all of the continental surface areas and they also have been identified on the ocean floors throughout the world. Geologically, manganese deposits are found in a wide range of environments, including: sedimentary, where they are associated with various types of sedimentary and volcanic rocks; hydrothermal, where the manganese was deposited under the influence of volcanic-hydrothermal activity; and residual, where manganese was concentrated in situ, by weathering processes, on a variety of host rocks. (A glossary containing many terms used in this report is provided after Chapter 7.) In many deposits of manganese there is evidence of overlapping of the environments of deposition and of the processes of formation. Different criteria have been used by different workers to classify manganese deposits (Park, 1956; Varentsov, 1964; Roy, 1969 and 1976; and Dorr, 1973). The system used herein reflects the outline proposed by Roy (1969, 1976).

3.2.1 Sedimentary Deposits

The deposits of sedimentary origin make up the largest group of economic manganese occurrences in the world. These deposits can be divided into two main types: volcanogenetic-sedimentary or nonvolcanogenetic. (Krauskopf, 1967; Stanton, 1972). This classification depends respectively upon the source of the manganese that was derived from volcanic activity in the former, or from the weathering of crustal rocks in the latter (Roy, 1976). Manganese deposits are found in association with different lithologic types that range from clastic sediments of varying composition to iron formations and carbonate rocks. They are also found in varying tectonic frameworks ranging from mobile geosynclinal belts to stable platform areas. The different environmental conditions within which manganese can be deposited tend to overlap, with the end result that manganese can be associated with clastic sediments, iron formations, or carbonate rocks in either a geosynclinal or stable platform structural setting.

The distribution of manganese deposits in geologic time ranges from Precambrian to Cenozoic, although the volume of sedimentary manganese varies greatly from one time period to another. About 10% of the world's known manganese ores are found in Precambrian rocks, and lesser concentrations are found within the succeeding rocks of the lower Cambrian and mid-Paleozoic. There were no significant manganese occurrences known in Mesozoic rocks until recent discoveries of resources were reported at Groote Eylandt, Australia and Molango, Mexico. By far the largest known accumulations of terrestrial manganese are those which occur within Cenozoic rocks.

Occurrences of manganese of early Precambrian age were most commonly associated with geosynclinal mobile tectonic environments, whereas those of the Cenozoic are found largely in stable platform settings. The largest known manganese resources, those which can be calculated in the hundreds of millions of tons, are those sedimentary accumulations found in tectonically stable platform areas. Varentsov (1964) has calculated that 73% of the known terrestrial manganese is in the Cenozoic platform deposits of southern USSR (i.e., Nikopol'). Also included as sedimentary deposits are the sea-bottom accumulations of manganese nodules.

The manganese which contributes to the sedimentary deposits can be derived from the weathering of the continental land masses, the weathering of volcanic rocks, and the volcanic and/or hydrothermal exhalations into either a terrestrial or marine environment. Whatever the source of the manganese, once it is introduced into a standing body of water, it becomes subject to the processes of sediment transport and deposition. The environment of the depositional site influences the character of the resulting deposit. Manganese deposited in a near-shore, strongly oxidizing environment, with relatively free water circulation, will be in the form of oxide minerals and can be associated with a variety of clastic sediments. In this environment, and because of the high concentration of oxygen, carbonaceous material is either absent or in low concentration. Conversely, the manganese deposited in a reducing environment at greater depths or in closed basins will be in the form of carbonates or will be associated with carbonate and sometimes clayey carbonaceous material (Dorr, 1973).

The sedimentary deposits of manganese can be divided into several broad classifications as follows:

1) Volcanogenic includes those sedimentary deposits in which the manganese can be related directly or indirectly to volcanic sources. These can include manganese released by the weathering of volcanic rocks, or manganese from direct volcanic activity,

i.e., from volcanic exhalations or from the reactions between volcanic rocks and marine waters during subaqueous volcanic eruptions. Evidence for the volcanic derivation of those deposits could include a close spatial association of the manganese beds with volcanic rocks, interbedding of the manganese and volcanic rocks, an association with hydrothermal deposits, and an association of the manganiferous rocks with hypogene alterations. Some of the manganese occurrences considered in this category are the deposits in Morocco, Sweden, Nsuta in Ghana, and in the Olympic Peninsula in the United States.

2) Nonvolcanogenic sedimentary deposits include those where the manganese was not related to any volcanic source, but was derived from the weathering of a continental land mass, transported by streams, and subsequently deposited in standing bodies of water adjacent to the land areas. Depending upon the environment of deposition, the manganese mineralogy could be predominantly oxides or carbonates as previously described. These manganese deposits are frequently associated with orthoquartzite-glauconite clays and/or carbonate formations. The mineralogy of the deposits generally consists of higher oxides (pyrolusite) that in some instances are known to grade off laterally into manganiferous limestones-dolomites and manganocarbonates. These deposits, sometimes referred to as a "pure sedimentary" type, comprise some of the more important known manganese deposits, i.e., Chiatura and Nikopol' of USSR; Morro do Urucum, Brazil; and Madhya Pradesh-Maharashtra, India.

3) Manganese deposits are also associated with meta-sedimentary iron formations of probable Precambrian age as in the Postmasburg and Kuruman (Kalahari) areas of South Africa, Minas Gerais and Morro do Urucum of Brazil, and Maliy Khingan in USSR. The manganese beds were probably deposited both as low-grade carbonates and/or oxides in close association with the iron formation. Opinion varies regarding the genesis of the deposits; however, in some instances it has been noted that the original protore may have been secondarily enriched by supergene processes prior to its being subjected to metamorphism. The iron formation units are extensive and have been traced laterally over great distances, whereas the associated individual manganese beds may vary in thickness and continuity along strike.

4) Sedimentary accumulations of manganese cover vast areas of the floors of the North and South Atlantic, North and South Pacific and the Indian Ocean. The manganese occurs as individual nodule accretions or as welded sheet-like beds of nodules forming extensive pavement-type accumulations on the ocean bottom. The nodule sizes range from a few millimeters to several tens of centimeters in diameter. The thickness of the accumulations is relatively thin and it is reported that the upper 30 cm of the sea bottom may contain about 65% of the useful material (Dorr, 1973).

The higher grades of manganese nodules are found within the deeper ocean basins at greater distances from the land areas where clastic sedimentation was minimal. The manganese content of the Pacific nodules is higher than that of the Atlantic, as shown in the following table (Weiss, 1977):

TABLE 3-1
COMPARISON OF PACIFIC AND ATLANTIC
MANGANESE NODULE GRADES (PERCENT DRY WEIGHT)

	Pacific	Atlantic
Manganese	29.8	15.7
Nickel	1.36	0.59
Copper	1.2	0.14

The origin of the manganese is considered to be varied and is probably derived from several sources: submarine volcanism; subaqueous alteration of manganese-bearing volcanic rocks; diagenesis within the bottom sediments, accompanied by the upward migration of manganese to the seabed surface; and the deposition of manganese derived from the subaerial erosion of the continental land masses. Resources have not been accurately measured but they are considered to be vast.

3.2.2 Hypogene and Exhalative Deposits

Hypogene manganese deposits are those that were emplaced by thermal waters rising from the earth. The source of the waters and its dissolved mineral component could be from crystallizing igneous rocks or they could be heated ground waters that acquired their mineral content while circulating through the upper mantle and crustal rocks. As thermal waters rise toward the surface, they undergo temperature and pressure changes and constantly change their chemical composition as they react with the enclosing rock. They deposit a part of their chemical burden along the channel ways, while taking other constituents into solution. The resulting mineral accumulations occur as vein deposits in fractures and as replacements usually associated with intrusive and volcanic rocks. These types of deposits are made up of carbonate and oxide manganese minerals, along with other hydrothermal minerals such as barite, fluorite, sulfides, etc.

Examples of hypogene-hydrothermal vein type and replacement deposits include Butte and Phillipsburg, Montana, the San Juan region of Colorado, and various localities in the southwest United States, Japan, USSR, and Morocco. The present-day deposition of manganese is reported from a number of active hot springs in the western United States and in Japan. These types of deposits are generally quite small. The subaqueous exhalation of manganese-bearing hydrothermal solution directly into the oceans is believed to have contributed in part to the accumulation of seabed manganese nodules.

3.2.3 Metamorphosed Deposits

Subsequent to their emplacement, some manganese deposits of either sedimentary or other origin have been subjected to thermal and/or dynamic metamorphism, which resulted in internal changes to the original deposit. In some cases the metamorphism may have affected the grade of the manganese minerals by slight decrease in their degree of oxidation and correspondingly slight changes in their manganese content. In other cases the metamorphism induced reactions between the primary manganese minerals and contained impurities (i.e., SiO_2) and converted them to manganese silicate mineral-bearing rocks such as gondites, which rarely have commercial value. Roy (1976) summarizes as follows: "Many of these deposits have later been modified by thermal or regional metamorphism or both... In all cases, the effect of metamorphism is limited to reconstitution of mineralogy and texture of the pre-existing orebodies and no particular improvement of tenor took place by this process."

3.2.4 Surficial-Residual Deposits

Residual deposits are formed near the surface by the supergene processes of leaching and residual enrichment of either existing manganese deposits or low-grade manganese-bearing protore. Changes in oxidation states and circulating ground water are factors influencing the alteration and mobilization of the manganese minerals (see Table 3-2 for formulas for some manganese minerals). These concentration processes are similar to those that form lateritic iron, bauxite, and nickel deposits. The residual manganese cappings are made up of the minerals pyrolusite, cryptomelane, and manganite. The manganese in the protore includes disseminated manganese carbonates and silicates in low concentration in shales, phyllites, dolomites, and gondites. The formation of the residual manganese caps is usually above the level of the water table. The residual concentration processes increase the manganese content, and deposits of this type generally contain the higher grades of manganese ores.

Residual deposits of manganese are the most commonly noted occurrence. They range in size from small boulder-sized masses to large deposits of great economic significance. Included among the latter are those manganese deposits of Amapa in Brazil, Piedra Negra in Mexico, Moanda in Gabon, Ghana, and many of the deposits in Australia and India.

3.3 END-USE CONSIDERATIONS

Many ores furnish a single product or metal where there is little range in product quality (e.g., copper), but manganese ores and concentrates from them have a wide range of product quality. Thus, the oversimplification of generally assuming that one ore can limitlessly substitute for another leads to a misconception when strategic considerations are involved. For example, some USSR concentrate has a

TABLE 3-2. CHEMICAL FORMULAS OF SOME MANGANESE MINERALS

MINERAL	CHEMICAL FORMULA
Alabandite	MnS
Bementite	$2MnSio_3\ H_2O$
Bixbyite	$(MnFe)_2o_3$
Braunite	$3(MnFe)_2O_3\ MnSio_3$
Cryptomelane	$K_2Mn_8O_{16}$
Hausmannite	$MnMn_2O_4$
Hollandite	$MnBaMn_6O_{14}$
Jacobsite	$MnFe_2O_4$
Kutnahorite	$(CaMn)\ (CO_3)_2$
Lithiophorite	$LiMn_3Al_2O_3\ 3H_2O$
Manganite	$MnO(OH)$
Manganocalcite (Manganoan Calcite)	$(CaMn)CO_3$
Manganosite	MnO
Nsutite	MnO_2
Partridgeite	Mn_2O_3
Piedmontite	$Ca_2\ (Al,Fe,Mn)_3\ (OH)Si_3O_{12}$
Polianite	MnO_2
Psilomelane	$(Ba,H_2O)_2\ Mn_5O_{10}$*
Pyrolusite	MnO_2
Ramsdellite	MnO_2
Rancieite	$(Ca,Mn)Mn_4O_9\ 2H_2O$
Rhodochrosite	$MnCO_3$
Rhodonite	$MnSiO_3$
Spessartite	$Mn_3Al_2Si_3O_{12}$
Tephroite	Mn_2SiO_4
Todorokite	$(Mn,Ba,Ca,Mg)Mn_3O_7\ H_2O$
Wad	An impure mixture of manganese and or other oxides. No definite chemical formula.

*Highly variable

Mn content sufficiently high to be usable in the market economies, but the physical character and phosphorous content make it a handicapped substitute. Certain South African materials are high in basic carbonate compounds (and low in MnO_2) that would increase electric furnace slag volume and thus power consumption to 1.4 times the base. High-use proportions would result in erratic furnace operation and increased energy cost (Borden, Presentation to the Panel, 1979).

The following considerations assume present use practice of which the major factor is the predominant production of standard (78% manganese) high-carbon ferromanganese (FeMn). (Domestic ferromanganese standards of certain countries, for example Japan and Mexico, specify lower manganese content, in the 70%-73% range, but these exceptions do not greatly affect the general consideration.)

3.3.1 Metallurgical Ore--Desirable Characteristics

The best ores (or blends) for manganese ferroalloy production should have a manganese to iron ratio of 7.5 to 1, be easily reducible, minimize energy consumption, be low in contaminants, have good physical structure, and produce manageable amounts of slag. There are no standard specifications to cover these properties. Size and chemistry are mentioned, but these alone do not reveal the entire degree of suitability from the furnace operator's standpoint.

The ferroalloy industry has the electric furnace technology to produce 1980 specification 78-80% standard ferromanganese from almost any combination of manganese ores which will provide a blend containing a manganese content of 25% or more, a manganese to iron ratio of 7.5 to 1 or higher, and a phosphorus content of 0.13% or less. If the industry standard for ferromanganese were reduced to 75% manganese in the alloy, the required manganese to iron ratio could be reduced to 5.5 to 1.

1980 competitive economics, however, require the use of the highest manganese content ores in order to achieve the lowest cost of ore transport, electric energy, reducing agents, labor, and capital investment per unit of ferromanganese produced. Achieving the optimum balance of these factors in the furnaced ore blend which is unique to some degree for almost every electric furnace in the world, requires computer collation and evaluation of the factors introduced by each specific ore, for each furnace.

The higher purity ores available in the world today have SiO_2 + Al O_3 contents ranging from 4.5% to 11%, requiring the electric furnace to consume energy and reducing agent in the smelting of these slag-producing compounds. To recover the investment in power and reducing agent, many producers employ a "slag-recycle" operating practice to produce a slag containing +30% manganese for subsequent use in the production of silicomanganese alloy. By this method, 95% or more of the manganese content in the ore may be converted to usable product.

Using this slag-recycle practice the original ore blend must contain a higher manganese to iron ratio of not less than 8.5 to 1 for 80% standard ferromanganese and 6 to 1 for 75% standard ferromanganese.

For the purposes of this study, it should be noted:

1. Although the technology exists for the production of ferromanganese from low purity ores, the U.S. capacity for ferromanganese production would be more than proportionally reduced.

2. The costs of energy, reducing agent, labor and transport costs vary for each producer. Variations in these factors permit South Africa to produce competitive ferromanganese using a blend of native ores which could not be economically considered in the U.S. Similarly, Mexico has used a base ore of 27% manganese content via pre-reduction in a nodulizing kiln to produce a 39% manganese nodule, which was in turn used as the "ore" feed to the electric furnace.

Generally the high- and medium-grade ores are used in alloy production. The lower-grade ores, with less than 35% manganese plus about 20% iron content, are used in blast furnace additions to manganize the hot metal. However, as Table 3-3 shows, some high-grade metallurgical ore is also used in blast furnace additions. The total world pattern is unclear, but recently has been elucidated to some extent in the International Iron and Steel Institute (IISI) survey of manganese ore use.

3.3.2 Blending

Because of the complex factors involved, the nonintegrated producers consider blending of ores a preferred policy and, in fact, it is the almost universal policy. This means that no one ore, however good, would be used exclusively since the alloy producer will obtain some commercial benefit by using lower cost off-grade ores as well. The United States, United Kingdom, Japan, and Canada use five or more ores in blends. Generally a minimum average of 37% manganese in the blend is tolerated.

On the other hand, a country or producer that has both its own manganese ore and a ferroalloy industry (integrated producers) has a tendency to make the most use of its own ores, even if they are of indifferent quality (Borden, 1979). As an illustration, for internal consumption Mexico uses its own Molango sintered nodules (37% manganese) to make nonstandard ferromanganese. However, it imports high-grade ore (from Brazil and Gabon) to blend in amounts of 30%, with local sinter when making standard ferromanganese for re-export (see references under Mexico). Because of the good quality of its single, significant, high-grade source and the varied concentrator products, Australia's ferromanganese producer does not need to import blending ore. However, those products that are more difficult to market, such as fines from the mine, are sintered. This currently comprises 65% of the ferromanganese burden, the balance being lump.

Table 3-3. Illustrative Pattern of Manganese Ore Use for Major End Uses; Ferroalloys (1,000 metric tons)

	1978 France	1978 Australia	1978 United Kingdon	1978 United States	1978 South Africa (ISCOR)	1978 Japan	1977 Canada	1978 West Germany
Natural Tons of Ore* Consumed	960.0	364.0	230.0	1162.5	205.0	2490.0	182.2	654.0
Manganese Contained	432.0	168.0	95.0	N.A.	75.9	1070.7	N.A.	251.7
Calculated Grade	45.0%	46.2%	41.4%	48%**	37%	43.0%	49.8%	38.5%
Ore* Consumption								
Ore Used in Blast Furnace Additions	80.0	96.0	84.0	199.3	117.0	1000.0	0	208.0
Ore for Manganese Ferroalloys	865.0	247.0	140.0	754.9	88.0	1330.0	179.7	446.0
Other Ore Uses	15.0	21.0	6.0	208.3	N.A.	160.0	2.4	0
Total Ore Consumption	960.0	364.0	230.0	1162.5	205.0	2490.0	182.2	654.0
Total Metallurgical (High-Grade) Ore* Used in Blast Furnaces, Percent	low	28.0%	0%	20.9%+	57.0%	low	0%	0%
Manganese Ferroalloys Produced	396.5	96.6	73.0	376.1	34.6	760.0	93.3	211
Ratio Metallurgical Ore*/Alloy Produced	2.18	2.55	1.92	2.54	2.54	1.75	1.93	2.11

*Contains 35% or more manganese (natural).

**Calculated grade percent imported (497,000 m.t.) = 50.8% (natural)

N.A. = Not Available.

+ Ore used in blast furnaces (pig iron) as percent of tatla used for metallurgical purposes.

SOURCES: Data from U.S. Bureau of Mines; International Iron and Steel Institute; and personal communication from W. A. Preston.

While South Africa has a rather important amount of 38% manganese material, with good manganese to iron ratio (8/1), this more abundant material is not used exclusively for alloy production in the (reportedly cheaper) electric furnaces. However, it is used in blast furnace production for domestic consumption. Samancor's principal ore supplies are from the high-grade underground Wessels mine (the substitute for the now-exhausted Hotazel mine of similar quality), having 47% manganese, 12-14% iron (Mn to Fe ratio of 3.5-4 to 1); and the open-pit but lower-grade Mamatwan mine with 38% manganese, 5% iron (Mn to Fe ratio of 9/1) in about equal proportions. The reserves of the two mines are not in equal proportions, but rather in the proportion of 1 Wessels/3.3 Mamatwan. Streicher (1979) mentions that the high-grade ore (+44% manganese) is only 2.5% of the total resources and is mined preferentially. It would appear that the decision to open the underground Wessels mine, rather than expansion of open-pit Mamatwan production to supply all ore desired, is based on metallurgical considerations. Thus, blending of only indigenous ores was a necessary practice.

South African recognition of this consideration is illustrated in Featherstone's comment to the First International Congress on Ferroalloys, Johannesburg, April 1974:

> Mamatwan ore is singled out for further consideration and it is shown to be unsuitable for the production of high-carbon ferromanganese in the electric furnace. It is clear that Mamatwan ore is unsuitable for the electric-furnace production of high-grade 40% MnO slag and, although it can be used for the production of 20% MnO slag, the results do not compare favorably with overseas practice.

The reference considers the evident alternative, which is to use Mamatwan ore in blast-furnace production of ferromanganese, and particularly in a low-shaft furnace specifically designed for the alloy production rather than in an iron blast furnace. Other considerations then come into play as described by Featherstone (1974):

> On the other hand, the scarcity of good metallurgical coke cannot be ignored, and especially in countries having limited reserves of good coking coal, such as South Africa, it stands to reason that the established iron furnaces are to be given priority.
>
> Form coke and anthracite have been mentioned as possible replacements for metallurgical coke...both the enormous deposits of manganese ore suitable for blast-furnace reduction (Mamatwan) and the looming shortage of metallurgical coke in this country render it imperative that an economic substitute should be found speedily.
>
> It is claimed by Durrer and Volkert that the world's reserves of high-grade manganese ore amount to approximately 500 million m.t.'s. Mamatwan-type ore, which so far has not been regarded

> as belonging to this classification, possibly totals the same amount. It has been shown that, compared with other ores, Mamatwan ore is not regarded as suitable for submerged-arc furnaces, but can be used effectively in blast furnaces, and, therefore, by introducing such a process, we stand to double the quoted ore-reserve tonnage.

In the ensuing discussion it was stated:

> In the Transalloys operation, the proximity to the source of ore, and the ability to produce a high-manganese content in the alloys, appear to make the delivered cost of the alloy to Europe or America competitive. It is doubtful whether a production operation located in these overseas markets could be economic if based only on Mamatwan ore since the transportation cost per manganese unit would be very high from the mine to Europe or America.

In view of the preponderant quantity of Mamatwan-type ore in the South African resource base, the above comments imply that the limitations on use make the large quantity of that material in the ground of lesser importance than simple abundance would indicate. In fact, the South African ferroalloy industry perceives a problem: its competitive position is based on inexpensive electric power and electric furnaces, whereas the most abundant manganese material appears better suited for a low-shaft blast furnace for which there is no natural energy cost advantage.

Brazil also blends. Although it has both high- and mediocre-grade manganese ores, high-grade ore is imported from Gabon. This is a matter of economics as the high-grade Amapa ore in the north costs more to deliver to Brazilian furnaces in the south than some imported ore.

It is evident that ores which give the best furnace performance will be used preferentially. These are generally the high-grade ores, but they will be blended to some degree for technical and economic reasons. In other words, the various manganese ores complement rather than substitute for each other. Thus, the amount of certain less than ideal ores that are used is conditioned by the availability of the more suitable grade material with which to blend them. However, regardless of abundance, some ores will be used only in certain manageable proportions unless current practice changes. Thus, under present conditions the quantity of reserves or resources of some ores is not so important as the extent to which they will be used. If that use is less than the quantity base, the reserve or resource tonnage number does not provide the full picture. It is recognized that deposits of low-grade ores will eventually become a source of supply. This will be determined by the economics of the mining activity relative to the world market and the development of the needed technology to exploit these sources.

3.3.3 Battery Grade

Satisfactory performance of battery grade ores is usually the determining factor in their use and chemical composition can vary over rather wide limits. The Moanda, Gabon, battery-grade dioxide that dominates the market contains 83.64% MnO_2. Other ore grades are as follows: Ghana--78% MnO_2; Mexico 76% MnO_2; and Greece--67% and 74-75% MnO_2.

Weiss (1977) states:

> The physical and chemical properties of manganese dioxide required or desirable for the battery cathode have not been well established. At a symposium on manganese dioxide in Cleveland in 1975, the Electrochemical Society stated that 'the electrochemical behaviour of manganese dioxide in the battery is influenced by crystal structure, surface area, pore size distribution, shape and size of the particle, electrical conductivity, surface conditions, chemical composition, various impurities (H_2O and foreign elements) and defects in the structure.
>
> Several factors control the suitability of manganese ore for dry-cell manufacture. Chemically, the ore should have high oxygen availability for the cell hydrogen reaction, a minimum of iron and should be free of copper, nickel, cobalt, arsenic and other metals electronegative to zinc. Physically, the ore should be somewhat hard but porous. Since it is believed that the depolarising action in the cell is a surface reaction (i.e., starts at the surface but diffuses throughout the particle), the porous ore is able to react throughout its mass, not only on the outer surface. MnO_2, with higher water content, is more suitable as a depolariser. It is thought that water in any form plays an important role during the discharge of MnO_2; that it helps the proton migration and that the reaction can proceed more readily through the built-in water.

3.3.4 Chemical Grade

Weiss (1977) gives the following:

> There is no such thing as a chemical-grade manganese ore. There is only a manganese ore that is used in chemical applications because of its oxygen content or because for one reason or another it is suitable for use in the production of manganese compounds and chemicals, in agriculture, in welding, in ceramics and a wide range of other industries. Multi-purpose ores are increasingly used to produce chemicals such as hydroquinone, potassium permanganate and other permanganates, as well as alloys, metal and synthetic manganese dioxide.

There are a few manganese deposits that produce ore specifically for their oxygen content. The Imini mine in Morocco sells its product on the basis of manganese dioxide; the Transvaal deposits of South Africa are mined almost exclusively to provide manganese dioxide for domestic uranium oxide production. But hundreds of thousands of tons of manganese ore classified as 'metallurgical' are used in nonmetallurgical applications.

3.3.5 Present World Distribution of Product for Different End Uses

The following estimated world distribution is for the year 1977, which is the most recent year for which the BOM has published world production data (U.S. Bureau of Mines, 1977). The nonmetallurgical use data have been largely derived from Weiss (1977).

8.4	million m.t. high-grade produced and used for ferromanganese;
1.7	million m.t. low-grade blended with high-grade for ferromanganese;
10.3	million m.t. low-grade used in other than ferromanganese use; and
1.4	million m.t. special grade for nonmetallurgical uses.
21.8	million m.t. total.

It is estimated that about 10.3 million m.t. of high-grade ore were produced in 1977. The excess 1.9 million m.t. above the 8.4 million m.t. of high-grade ores in the listing above were used as direct blast furnace additions or for other uses. The battery-grade ores are also high-grade but are not included in the above cited 10.3 million m.t. of high-grade ore.

A scan of the literature indicates that a worldwide metallurgical balance has not been published and the above is an attempt to make an approximate distribution. It is also apparent that the steel companies may incorporate more low-grade manganese than shown as a blend with high-grade ore to make ferromanganese alloys. Consequently, the tonnages indicated above may be illustrative only.

3.4 SIGNIFICANCE OF GRADE RANGE AND MINERALOGY*

One of the more difficult charges given to this panel was to distinguish ore reserves by using United States Geological Survey

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*For additional information, see Deposit Subheadings in Part II.

Bulletin 1450-A criteria (Table 3-4 and in Appendix A), that are economic today, from resources that may become economic under certain postulated conditions. As can be appreciated, this can be done only in an approximate way since the interactions are very complex. These factors include the wide quality range of the manganese materials, varied mining conditions, geography of ore usage (transport factors), geography of deposits, the size of deposits, and its industrial practice as to useability.

During the course of this worldwide review, it was apparent that there is a sharp difference in the classification criteria for ore versus resource between the free market and countries with centrally planned economies. The centrally planned economy countries' criteria of acceptability are much less stringent and their economies are viewed differently, primarily because of their emphasis on self-sufficiency. Since the panel had no access to the economics of the various entrepreneurs, the classification had to be made using whatever benchmarks were available. These are reviewed below. The reader is reminded that all categories of mineral resources are dynamic. They are alterable by changing conditions such as mining technology advances, local and world economic conditions, end-use requirements, and depletion factors.

3.4.1 Manganese Content

For the USSR, certain factors were very explicitly stated in the literature. For example, at Tchiatura the minimum economic cut-off criteria in the secondary recovery operation were 0.8 m thickness, and 15% manganese. This does not mean that a deposit 0.8 m thick and 15% manganese is economic. Rather, it suggests that material having the minimum criteria could be incorporated in the quantity computation of the better material without having an unacceptably low average. Material presently mined is presumed to be economic. The bulk of this is Nikopol' ore of very low grade, averaging about 22% manganese, that under the mining conditions would be only submarginal resource material in the West. However, it is mined for self-sufficiency reasons. Where Nikopol' material is carbonate and contains only 13% manganese, it is called low-grade. Other references characterized +20% manganese near the Caspian Sea as economic, while in the Far East 18-20% manganese is called uneconomic.

One high-grade deposit, Tambao in the Voltaic Republic, that would be economic in another context, had to be classified as resource because the costs of transport do not permit profitable development at this time. In central Brazil, 34% manganese carbonate material is economic under special local use conditions, whereas all Brazilian high-grade deposits are obviously economic, as are the Gabon and Australian open-pit deposits. In socialist countries other than the USSR, local materials of less than 25% manganese are resource unless they are open-pit or shallow (cf. Hungary, Bulgaria, Rumania). Because the centrally planned economy countries' satellites are importing increasing amounts of Western high-grade ore, most of the local material was classified as a resource.

TABLE 3-4. GLOSSARY OF RESOURCE TERMS*

RESOURCE--A concentration of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible.

IDENTIFIED RESOURCES--Specific bodies of mineral-bearing material whose location, quality, and quantity are known freom geologic evidence supported by engineering measurements with respect to the demonstrated category.

UNDISCOVERED RESOURCES--Unspecified bodies of mineral-bearing material surmised to exist on the basis of broad geologic knowledge and theory.

RESERVE--That portion of the identified resource from which a usable mineral and energy commodity can be economically and legally extracted at the time of determination. The term ore is used for reserves of some minerals.

The following definitions for measured, indicated, and inferred are applicable to both the Reserve and Identified-Subeconomic resource components.$^+$

MEASURED--Reserves or resources for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes and for which the grade is computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are spaced so closely and the geologic character is so well defined that size, shape, and mineral content are well established. The computed tonnage and grade are judged to be accurate within limits which are stated, and no such limit is judged to be different from the computed tonnage or grade by more than 20 percent.

INDICATED--Reserves or resources for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to permit the mineral bodies to the outlined completely or the grade established throughout.

DEMONSTRATED--A collective term for the sum of measured and indicated reserves or resources.

INFERRED--Reserves or resources for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on an assumed continuity or repetition, of which there is geologic evidence; this evidence may include comparison with deposits of similar type. Bodies that are completely concealed may be included if there is specific geologic evidence of their presence. Estimates of inferred reserves or resources should include a statement of the specific limits within which the inferred material may lie.

TABLE 3-4. GLOSSARY OF RESOURCE TERMS* (continued)

IDENTIFIED-SUBECONOMIC--Resources that are not Reserves, but may become so as a result of changes in economic and legal conditions.

PARAMARGINAL--The portion of Subeconomic Resources that (1) borders on being economically producible or (2) is not commercially available solely because of legal or political circumstances.

SUBMARGINAL--The portion of Subeconomic Resources which would require a substantially higher price (more than 1.5 times the price at the time of determination) or a major cost-reducing advance in technology.

HYPOTHETICAL RESOURCES--Undiscovered resources that may reasonably be expected to exist in a known mining district under known geologic conditions. Exploration that confirms their existence and reveals quantity and quality will permit their reclassification as a Reserve or Identified-Subeconomic resource.

SPECULATIVE RESOURCES--Undiscovered resources that may occur either in known types of deposits in a favorable geologic setting where no discoveries have been made, or in as yet unknown types of deposits that remain to be recognized. Exploration that confirms their existence and reveals quantity and quality will permit their reclassification as Reserves or Identiffied-Subeconomic resources.

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*General guides for the use of this classification system are as follows:

1. Resource categories and definitions in the classification, as specified in the glossary, should be applicable to all naturally occurring concentrations of metals, nonmetals, and fossil fuels. The categories may be subdivided for special purposes.

2. Definitions may be amplified, where necessary, to make them more precise and conformable with accepted usage for particular commodities or types of resource evaluations.

3. Quantities and qualities may be expressed in a variety of terms and units to suit different purposes, but must be clearly stated and defined.

+The terms proved, probable, and possible (used by the industry and economic evaluations of ore in specific deposits or districts) commonly have been used loosely and interchangeably with the terms measured, indicated, or inferred (used by the Department of the Interior mainly for regional or national estimates). The terms "proved" and "measured" are essentially synonymous. The terms "probable" and "possible," however, are not synonymous with "indicated" and "inferred." "Probable" and "possible" describe estimates of partly sampled deposits--in some definitions for example, "probable" is used to describe deposits sampled on two or three sides and "possible" for deposits sampled only on one side; in the Bureau-Survey definitions, both would be described by the term "indicated."

South Africa has a notable position from the resource-abundance standpoint and available criteria plus judgment had to be used to identify the reserve portion. High-grade ore mined at 400 m depth (Wessels) is obviously economic, as is medium-grade ore mined in open pit with a 3/1 strip ratio (Mamatwan). On the other hand, it appeared that the new entrant, Middelplaats, mining 37.9% manganese ore at 400 m depth, was hardly profitable under late 1979 conditions.* Consequently, material averaging less than 38% manganese at depths below 300-400 m was placed in the resource category.

In the People's Republic of China, the deposits considered of economic value are the exogenous ones, i.e., sedimentary and residual. The chemistry provided for certain occurrences indicates a number with nearly equal iron and manganese content. These are excluded as ferruginous manganese ore, as are others with preponderant iron. Those manganese carbonate ores with low iron appear to be considered economic where manganese content is as low as 17-23% manganese. Material considered to be of the best quality is oxide secondarily enriched from carbonate and grades 30-36% manganese, with low phosphorus but high silica, e.g., 10-25%.

3.4.2 Manganese Mineralogy

From the mineralogical standpoint, metamorphosed resources with abundant manganese silicates are considered worthless today. Manganese carbonate ore with 20% manganese, whether deep-stripped or underground mined, was generally considered a resource in the West, but in the East it is mined in some instances and is therefore a reserve although economically marginal.

Because half the ore in the Caucasus (USSR) contains greater than 15% SiO_2 and 12-22% manganese in carbonate, it was classified by the source reference as uneconomic. In the Far East, 18-22% manganese carbonate ore is uneconomic due to high silicate content. Manganocalcite with 20-25% manganese is classified as uneconomic where quantities are only in the tens of thousands of tons. Where 10% manganese-bearing limestone was mentioned as having possible local use in steelmaking additions, it was nevertheless excluded as unrelated to ferromanganese applications. Almost all Siberian "ores" have high phosphorus and carbonate content and are regarded by those describing them as subeconomic.

3.4.3 Blast Furnace Additions

All material described as of possible localized use as blast furnace or steel furnace additions, was excluded from reserves and resources. In general, material in international trade actually used for blast furnace additions, having 25-30% manganese and about 20% iron (ferruginous manganese ore), was also excluded as not within the charge to the panel. Likewise, manganiferous iron ore (up to 10% manganese) is not reviewed except where specific information suggests the manganese might be recovered separately as a resource.

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*At the time of writing (July 1980) manganese ore prices have improved about 30% over 1979 prices. The extent to which this improved the profit margin, in spite of rising production costs, is not known. It is assumed possibly that some resources have been changed to the reserve category.

3.5 RESERVE CATEGORIES AND RELIABILITY

Based on available knowledge, reserves in this report are categorized by the USGS/BOM classification. Table 3-4 gives definitions of the terms used in this review (Bulletin 1450-A, 1976, see Appendix A). Reserves are that part of resources which are economic to mine at the time of the categorization. For manganese, the economic criteria applied reflect both cost and current industrial practice. A minor difficulty arises in classifying some low-grade deposits that are economic to mine in limited quantities for nearby local use because transporting better material is expensive. Narrowly defined, such deposits are reserves, but if the local use disappears they revert to resources. Examples exist in Central Brazil, Kazakhstan, Siberia, Urals, South Africa, and elsewhere. However, these ephemeral reserves are not a large part of the world total.

The USGS/BOM classification places an accuracy of less than 20% error on tonnage and grade estimates for the measured category. For indicated ore, an error margin of less than 50% is assumed by the panel. No error margin is quantified for inferred ore. Where other countries have used terminology similar to the British system of proved, probable, or possible, the categories have been recast as if they were similar respectively to measured, indicated, and inferred. As Table 3-4 points out, there are differences of substance.

Many eastern countries and emerging nations receiving assistance from those countries with centrally planned economies use the revised USSR classification of 1953. This system employed in the USSR was adopted in 1960 by the Council for Mutual Economic Assistance (Centrally Planned Economy Countries). This system is summarized in Table 3-5. A + B are considered, for the panel's purpose, equivalent to measured; C_1 equivalent to indicated; and C_2 equivalent to inferred. The admissible error margin is less than 15% to 20% for A, less than 20% to 30% for B, and less than 30% to 60% for C_1. C_2 may have an error of less than 60% to 90%. More significant in the Soviet classification is the requirement that for a new mine, the quantity of reserves included in A + B should be at least 30% of A + B + C_1, and A alone should be at least 10%. This applies to simple structure deposits of fairly constant thickness and uniform mineralization such as some sedimentary manganese deposits.

The socialist countries' classification is more specific regarding the density of exploration by reserve category. For example, concerning stratabound manganese ores, the exploratory grid density recommended is 150 to 200 m for A, 300 to 400 m for B, and 600 to 700 m for C_1. However, C is usually limited in dipping bedded deposits to 300 to 400 m, i.e., within open pit reach.

TABLE 3-5. RESERVE DEFINITIONS FOR CENTRAL ECONOMY COUNTRIES

Category	Characteristics
A	Reserves assessed in such detail that their mode of deposition, the shape, and the structure of the ore body are fully defined; industrial minerals, their natural and technological types, interrelationships and distribution are determined; barren and noneconomic sectors are delimited; mining-technical (hydrogeological, engineering-geological) factors controlling exploitation and treatment of materials, and their quality and technological properties are determined precisely. Reserves of category A must be outlined by positive drilling or underground workings or other exposures.
B	Reserves explored in such detail that the principal peculiarities of their mode of deposition, the shape, and the structure are known; economic, natural and technical types of mineral materials are determined, as well as regularities in their distribution, but not their precise spatial delimitation. Inside the ore bodies, the character of barren and unsatisfactory sectors and their relationship to economic sectors are determined; barren and unsatisfactory sectors are precisely delimited. The quality and technological properties of the ore and mining-technical factors (hydrogeological, engineering-geological, etc.) that control the working and treatment are determined. The outline of B category reserves must pass through positive drill holes mine workings or other exposures. If the thickness and quality of the deposit material is constant, a limited extrapolated zone can also be included in this category.
C_1	These reserves are assessed in sufficient detail that the conditions, shape and structure of the ore bodies are broadly outlined; economic types of ores, their natural and technological properties, and mining-technical factors determining the exploitation and processing procedures are defined in general. The appraisal of C_1 reserves is established from the results of borings, mine workings, exposures, and interpolation and extrapolation based on geological, geophysical, and other data.
C_2	Poorly explored reserves. The mode of deposiition, shape, and structure of the deposit are ddetermined on the basis of geological study and geophysical measurements, confirmed by opening of the deposit in several places, or by analogy with the explored sectors. The kind of ore, natural and technological types, and the quality are determined from the analyses of samples or from the results obtained in adjacent explored sectors. C_2 reserves are outlined according to the boundaries of favorable geological structures or rock complexes; on the basis of separate drill holes, outcrops, etc.; by interpolation and extrapolation based on geological, geophysical, and other data.

TABLE 3-5. RESERVE DEFINITIONS FOR CENTRAL ECONOMY COUNTRIES (continued)

Category	Characteristics
Possible Reserves	Unexplored resources presumed to exist on the basis of regularities governing the origin and distribution of mineral deposits and of the results of structural and historical-geological studies of the area in question. Parameters for the assessment of possible reserves (strike length, thickness, average content of useful minesals, etc.) are determined from geolegical hypotheses or are deduced. Possible reserves are not included in the national budget of mineral reserves; they serve only as a basis for planning geological exploration.

According to Chernyshev (1969) in the USSR the recommended reconnaissance grid for C_2 is 1,200 m x 1,200 m for syngenetic deposits associated with orthoquartzite. C_1 requires 300 to 400 m; B, 300 to 200 m; and A, 150 to 100 m, provided faulting is minimal (Nikopol', Tchiatura) and there is access to ore by existing shafts and cross-cuts. For volcanogene, hypogene, and exhalative, Chernyshev recommends a reconnaissance grid of 200 to 400 m; whereas for faulted stratabound but metamorphosed deposits (Urals), he prefers a grid of 100 m x 200 m (along strike) in reconnaissance and 50 m x 100 m in detail. For supergene oxidized mantles, he recommends pits on a 50 to 100 m grid for final evaluation, after 100 to 300 m reconnaissance grids.

Exploratory grid density of Western stratabound manganese deposits appear to be largely a matter of pragmatism, but (before a production decision) the information available to the panel suggests no greater than 125 m square grid for measured, and about 500 m for inferred, not very different from the East. As will be apparent to the reader from what is described below, the South African terminology is imprecise and the grid density is anomalous in its wide interval for quantified ore. It is even wider than initial exploratory grids elsewhere in both East and West. A comparison of some exploration and development densities is attached (Table 3-6). All are operating mine areas and all are shallow, except Middelplaats. For the shallow tabular bodies, after allowing for average thickness difference, the density of observation in South Africa for the same tonnage is one-half to one-quarter of that in other developed deposits.

3.5.1 Recoverable Manganese

One charge to the panel was to estimate recoverable manganese units. Where recovery factors were specifically known, for example the percent underground extraction and the percent recovery in beneficiation plants, they were actually applied. In many areas, fines are recovered as a resource for later utilization but may not be immediately marketable. Recovery losses for set-aside fines were recognized and the general range was 13-20% loss. On underground mining, which is principally by room and pillar methods, the recovery loss was assumed to be no less than 25% ore left in place, rising to 50% in very deep operations.

3.6 ASSESSMENT OF MAJOR MANGANESE RESERVES AND RESOURCES

Reserves and resources as evaluated by the panel are tabulated in Tables 3-7 and 3-8. The supporting data are in Part II, Sections A (major) and B (minor). The criteria employed here for the classification between reserves and resources were reviewed in Sections 3.2 and 3.3, while the criteria for classification as to reliability are in Section 3.5. The panel has endeavored to adhere as closely as possible to these guidelines and rules in compiling and categorizing these figures.

As mentioned in the Preface, this manganese resource evaluation (including the reserve portion) is an independent effort. The panel assembled a group of geologists who, in mutual consultation, contributed

TABLE 3-6. Comparison of Exploration Density of Some Manganese Occurrences

	Gabon	Brazil	Australia	USSR		South Africa	
	Moanda	Amapá	Groote-Eylandt	Tchiatura	Nikopol' E. Grushevsko-Basanskiy	Mamatwan & Goold	Middel-Plaats
Number of holes	359	168	1776	600 (modern)	250	246	35
Number of pits, trenches etc.	149 508	0 168	755 2531	120 km	NA*	0	0
Metric tons "measured" (m) or other (o) demonstrated by this work (millions)	200(m)	9.17(m)	150(m) 276(o)	218(m)	60(m)	650(m)+(o)	52(o)
Drill interval (meters)	500–1000 62.5 (final)	30–80 (final) 1/1600 m^2	240 60 (final)	200–400 100–200 (final)	350 100–200 (final)	1,400 150–200 60–75(final)	400–1000 300 (final)
Tons/observation point	240,000	55,000	170,000	350,000	240,000	2,600,000	1,500,000

* Not available

SOURCE: Information in this study.
Taljaardt, J. J. "Major Manganese Ore Fields, Republic of South Africa." Paper presented at European Economic Community Round Table on Manganese, Brussels, Belgium (December 5, 1979).

TABLE 3–7. Manganese Reserves (thousands of metric tons)

	Measured			Indicated			Inferred			
Country	Tons Crude (c) Product (p)	Grade Percent Manga-nese	Tons Recoverable Contained Manganese	Tons Crude (c) Product (p)	Grade Percent Manga-nese	Tons Recoverable Contained Manganese	Tons Crude (c) Product (p)	Grade Percent Manga-nese	Tons Recoverable Contained Manganese	Comments
USSR										
Nikopol'	389,600(c)	22	68,600	195,400(c)	22	34,400	6,800(c)	22	750	oxide, carbonate
Bol'she Tokmak	133,650(c)	18.5	19,700	856,350(c)	18.5	126,300	307,000(c)	18.5	40,000	carbonate, oxide
Tchiatura	155,000(c)	24.5	15,000	–	–	–	13,000(c)	24.5	1,250	oxide, carbonate
Other	57,900(c)	21-27	6,600	–	–	–	164,100(c)	21-25	19,900	mixed carb/oxide
Subtotal	736,150		109,900	1,051,750		160,700	490,900		61,900	
South Africa–Kuruman Dist.										
Middelplaats	52,600(c)	38	12,540	–	–	–	–	–	–	mixed carb/oxide
Wessels	135,000(c)	48	36,000	–	–	–	–	–	–	oxide, carbonate
Mamatwan	50,000(c)	39	15,600	200,000(c)	39	62,400	315,000(c)	39	86,300	oxide, carbonate
Ammosal Mines	134,000(c)	44	35,376	–	–	–	–	–	–	oxide
Postmasburg	–	–	–	15,000(c)	29	3,480	–	–	–	
Subtotal	371,600		99,516	215,000		65,880	315,000		86,300	
Australia–Groote Eylandt	150,000(p)	48	72,000	–	–	–	63,000(p)	48	30,240	oxide
Gabon–Moanda Area	69,000(p)	50	34,500	–	–	–	125,000(p)	50	62,500	oxide
Mexico										
Molango Dist.	500(c)	46	1,161	1,000(c)	46	322	–	–	–	oxide
Molango Dist.	10,000(c)	27	1,943	20,000(c)	25	3,000	200,000(c)	25	30,000	carbonate
Subtotal	10,500		3,104	21,000		3,322	200,000		30,000	
Brazil										
Serra Do Navio, Amapa	4,630(p)	48.3	2,236	1,158(p)	48.3	599	–	–	–	oxide, lump
Serra Do Navio, Amapa	1,854(p)	55.1	1,022	463(p)	55.1	255	–	–	–	pellets
Urucum, Mato Grosso	2,500(c)	46	690	14,500(c)	46	4,002	27,000(c)	46	7,452	oxide
Santana, Mato Grosso	–	–	–	600(p)	45.6	274	904(p)	45.6	412	oxide
Morro Da Mina, Minas Gerais	–	–	–	–	–	–	3,000(c)	27	810	carbonate
Marau, Bahia	–	–	–	–	–	–	4,000(p)	43	1,760	oxide
Subtotal	8,984		3,948	16,721		5,130	34,904		10,434	

China–All Mines	–	–	–	–	–	–	130,000(c)*	35	30,900	
India–All Mines	2,300(c)	38-48	495	6,900(c)	38-48	1,484	43,600(c)	38-48	9,374	oxide, silicate
Goa	–	–	–	850(c)	39	166	–	–	–	oxide
Subtotal	2,300		495	7,750		1,650	43,600		9,374	
Bulgaria										
Varna Dist.	1,145(c)	23.1	199	–	–	–	1,661	20.6	257	carbonate
Sofia	4.3(c)	29.8	1	–	–	–	–	–	–	carbonate
Subtotal	1,149.3		200				1,661		257	
Rumania–Iacobeni Area	–	–	–	15,000(c)	26	1,268	–	–	–	carbonate
Ghana–Nsuta	–	–	–	20,000(c)	30	3,536	–	–	–	carbonate
Morocco–Imini	1,800(c)	46	530	500(c)	46	147	1,300(c)	46	383	oxide
Zaire–Kisenge	1,200(c)	42.8	323	–	–	–	–	–	–	oxide
Zambia–Luwana	30(c)	53	10	–	–	–	–	–	–	oxide
Argentina–Farellon Negro	–	–	–	765(c)	32	118	–	–	–	oxide, carbonate
Chile–All Mines	–	–	–	–	–	–	2,500(c)	31	496	oxide
Venezuela	–	–	–	–	–	–	350(c)	40	112	
Turkey–Various	1,000(c)	36	288	3,000(c)	36	864	10,000(c)	36	2,880	
New Hebrides–Forari	–	–	–	85(p)	42	35	–	–	–	oxide
TOTALS (rounded)	1,354,000		325,000	1,352,000		243,000	1,418,000		326,000	
Total Reserve (rounded)		4,126,000								
Total Recoverable Manganese (rounded)		894,000								

Dash (–) denotes no data assigned by the panel to this category.

*The reserves listed for the People's Republic of China includes ferruginous manganese which the Panel was unable to quantify.

NOTE: The reserves of the other remaining producing countries are unknown but will not significantly alter the above totals.

TABLE 3-8. Manganese Resources (Thousands of metric tons) [Reserves not included are in Table 3-8]

	Submarginal			Hypothetical			
Country	Tons Crude (c) Products (p)	Grade Percent Manganese	Tons Recoverable Contained Manganese	Tons Crude (c) Products (p)	Grade Percent Manganese	Tons Recoverable Contained Manganese	Comments
USSR							
Krivoi Rog	–	–	–	50,000(c)	20	7,500	
Other	152,000(c)	4-25	12,000	9,000(c)	15-21.1	2,200	mostly carb/silicate
Subtotal	152,000		12,000	59,000		9,700	
South Africa–Kuruman Dist.	48,000(c)	36	8,900	–		–	carb/oxides/silicate
	1,468,000(c)	34	233,000	4,381,000(c)	34	596,000	carb/oxides/silicate
	444,000(c)	27	38,900	3,856,000(c)	27	338,400	carb/oxides/silicate
Subtotal	1,960,000		280,800	8,237,000		934,400	
Australia							
Groote Eylandt	–	–	–	32,000	48	15,360	oxide
Woodie Woodie	100(c)	52	42	–	–	–	oxide
Subtotal	100		42	32,000		15,360	
Mexico-Molango Dist.	–	–	–	1,300,000(c)	25	169,000	carbonate
	–	–	–	14,000,000(c)	10	525,000	carbonate
Subtotal				15,300,000		694,000	
Brazil							
Azul, Para	44,000(p)	46.5	20,460	–	–	–	oxide
Buritirama, Para	11,000(c)	40	3,300	–	–	–	oxide
Sereno, Para.	2,800(c)	20	420	–	–	–	oxide
Urucum, Mato Grosso	15,000(c)	47	4,230	–	–	–	oxide
Others	6,400(p)	43	2,752	–	–	–	
Subtotal	79,200		31,162				

Canada–Woodstock	193,000	9	6,080	–	–	–	carbonate/silicate
U.S.							
Aroostook Co., Maine	260,000(c)	8.9	5,785	–	–	–	silicate/carbonate
Aroostook Co., Maine	81,000(c)	9	3,645	–	–	–	silicate/carbonate
Artillery Peak, Arizona	159,000(c)	3.9	1,736	–	–	–	oxides
Batesville, Arkansas	178,000(c)	4	2,136	–	–	–	oxide/silicate/carb.
Cuyuna Range, Minnesota	247,000(c)	8	4,742	–	–	–	oxide/carbonate
Subtotal	925,000		18,044				
Argentina	1,335(c)	25	163	–	–	–	oxide
Guyana–Matthews Ridge	6,000(p)	41	2,460	–	–	–	oxide
Belgium	1,000(c)	12	50	–	–	–	carbonate/silicate
Bulgaria–Varna Dist.	15,729(c)	15.3	1,809	7,500,000(c)	10	337,500	carbonate
	10,362(c)	20.3	1,578	–	–	–	
Subtotal	26,091		3,387	7,500,000		337,500	
Hungary–Úrkút	215,000(p)	20.5	45,000	–	–	–	carbonate
Rumania							
Razoare Area	5,000(c)	19	309	–	–	–	carbonate/silicate
Banat Area	–	–	–	7,500(c)	20	488	carbonate
Yugoslavia	30,000(c)	26.5	3,895	–	–	–	
Botswana	100(p)	46.2	46	–	–	–	oxide
Ivory Coast–Ziémougoula	–	–	–	8,000(c)	26	1,456	oxide
Mali–Takavasita	7,700(c)	45	2,425	–	–	–	oxide
Namibia–Otjonsondu	3,700(c)	44	1,172	–	–	–	oxide/silicate
Upper Volta							
Tambao	16,100(c)	53.8	6,236	–	–	–	oxide/carbonate
Tambao	730(c)	49.8	262	–	–	–	oxide, detrital
Tiere	300(c)	37.5	84	–	–	–	oxide
Subtotal	17,130		6,582				
Zaire	8,000(c)	35	1,120	–	–	–	carbonate
Indonesia–Java	480(c)	29	89	–	–	–	oxide
Israel							
Timna	10,000(c)	23	1,150	–	–	–	oxide
Timna	560(c)	42	58	–	–	–	oxide, concretions
Subtotal	10,560		1,208				
Philippines–All areas	–	–	–	6,000(c)	47	1,692	oxide
Fiji–Viti Levu	310(p)	50	93	–	–	–	oxide
TOTALS (rounded)	3,642,000		416,000	31,150,000		1,995,000	

Dash (–) denotes no data assigned by the panel to this category.

their own estimate of the order of magnitude of major reserves and resources based on their own familiarity, during the last decade, with numerous western deposits. These included the major sources: Mexico, Bolivia, Brazil, Yugoslavia, Gabon, Ghana, South Africa, Upper Volta, Zaire, India and Australia. A special session was held in Pittsburgh, Pennsylvania in December, 1979 where the group, with panel representatives, considered the reasonableness of numbers to be assigned to various categories of the major occurrences. These judgments were based on all pertinent factors such as reliably established dimensions, depth, grade, possibility of persistence in the light of genetic type and known structural complications.

The group's estimates as they concern some major deposits were cross-checked and/or supplemented by presentations made to the panel by geologists. Where maps were available in source literature, a cross-check was made on quantities using areas reasonably expected to be underlain by mineralization even in the instances of some minor sources where no resource figure was offered by the reference. In the case of a single reference where there was no familiarity by the sub-group, the source reference numbers were nevertheless evaluated as to their reasonableness.

In the Central Economy Countries, resource categorization was much more specific and the judgment as to reserves of different categories and resources was less demanding. The primary contribution of the panel with respect to these countries was a review of more recent literature in the original languages and to contribute a reserve analysis by comparison with older references. For some areas in the West, bore-hole data, but little other deposit geometry, were available. Even when quite meager, such data can lend themselves to computer analysis. Consideration was given to using this approach, but the panel felt that recently published information on certain sparsely explored occurrences, coupled with the judgment of the geological group, was sufficient for its assessment.

Countries with significant reserves and production of high- and medium-grade ores and concentrates that are considered first-order factors in the present world manganese supply picture are Australia, Brazil, Gabon, India, Mexico, South Africa, and the USSR. A summary of the principal observations of these countries is presented in Tables 3-7 and 3-8 as a consolidation of values derived from a detailed analysis of currently available data. The reader is referred to Part II of this report for further information on each of the source countries discussed and on other identified sources included in this summary. Maps showing the location of these mines are included. The panel emphasizes the fact that the task of classifying resources is a highly dynamic one. What is in a specific category today could change when more information is generated or when circumstances arise to justify the reclassification of an identified reserve or resource.

3.6.1 Australia

After South Africa and Gabon, Australia ranks third among the free market countries in production of manganese ore. It ranks second after South Africa in terms of reserves and resources.

Virtually all manganese ore production in Australia comes from Groote Eylandt in the Gulf of Carpenteria, about 50 km off the coast of Arnhem Land in the Northern Territory. Annual capacity is about 2 million metric tons (m.t.) of various products, which average 49% manganese overall. Some 180 thousand tons are shipped from Groote Eylandt annually to a ferroalloy plant at Bell Bay, Tasmania. The balance of production is exported to Japan, Europe, and the United States. Imports from Australia comprised 13% of total U.S. imports in 1974-1977, but may be slightly less than that in 1979-1980.

The ore occurs as flat-lying bedded deposits of manganese oxides in the form of massive layers of boulders and cobbles, pisolites both loose and cemented in a matrix of laterized sandy clay or manganese oxides, and in alternating layers of pisolitic or textureless ore and sandy clay. The ore layer, which averages 3 m in thickness, lies where currently mined, under a cover of an average of 3 m of sandstone and clay. Mining is relatively easy and beneficiation involving crushing, screening, scrubbing, and heavy media separation of lump ore is sophisticated and efficient. Approximately 4 million metric tons of crude ore are mined to yield the annual production of 2 million metric tons of salable product. An increase to 2.3 million tons of product by 1985 is contemplated. Truck haulage from plant to shipping port is only 16 km.

Measured reserves are 150 million m.t. of product at 48% manganese. At 2 million m.t. of product annually, a life of 75 years seems assured. Additional reserves include an estimated 63 million m.t. of inferred product, and 32 million m.t. of product tentatively classified as hypothetical resource. Exploration on the mainland opposite Groote Eylandt has not located additional reserves. With total estimated resources on Groote Eylandt of 245 million m.t. of product at 48% manganese, relatively easy mining and efficient beneficiation, and short overland haul to the shipping port, Australia should continue to be one of the world's leading manganese ore producers and exporters.

3.6.2 Brazil

Brazil is the fifth ranking producer of manganese ore among the free market countries after the Republic of South Africa, Gabon, Australia, and India. Brazil produced about 9% of the world total of free-market producer countries in 1978 and was the second largest supplier to the United States after Gabon.

The Serra do Navio mine in the Territory of Amapa has been the largest producer and exporter of manganese ore since 1957. Serra do Navio is 196 km by rail north of the shipping port of Santana on the North Channel of the Amazon River. Production from 1957 through 1979 was about 21 million m.t. of washed ore grading 48.5% manganese. Annual capacity is 0.8 million m.t. of washed lump ore of the same grade. In addition to washed lump ore, a reduction roast-pelletizing plant utilizing nonmarketable fines was put into operation in 1975. The plant, located at the shipping port of Santana has a capacity of 0.2 million m.t. of pellets annually grading 55% manganese.

Mining at Serra do Navio is open-pit. The ore is manganese oxide, which formed thick cappings to 150 m wide along ridge crests. It extended as much as 130 m downward to the underlying protore and schistose rock. Most of the high-grade ore is hard and massive. Other ore types are schistose, gonditic, and lateritic (float) ore.

Identified reserves at Serra do Navio as of January 1, 1980, are 16.124 million m.t. of crude ore that will yield 5.788 million m.t. of lump ore product grading 48.3% manganese. Estimated reserves of intermediate and fine sizes from the washing plant will yield about 2.3 million m.t. of pellets. Continuing exploration may locate additional reserves around the fringes of the generally well-delineated deposits, but no major new discovery is anticipated.

Elsewhere in Brazil the best known deposits are in the Corumba District, Mato Grosso. At the Urucum mine, ore has been shipped sporadically in relatively small quantities by barge since 1912. Identified reserves total 44 million m.t. that, because mining is underground, will yield about 26 million m.t. running 46% Mn, 13% Fe, and nearly 4% K_2O. Transportation problems and the high iron and potash content are obvious drawbacks to full development of Urucum's potential. Resources in the Corumba area may total as much as 100 million m.t., but a great amount of exploration is needed to substantiate this.

In the Carajas district, Para, the Azul manganese prospect has promise of becoming an important producer when the railroad, presently under construction, to service the iron ore operations is completed. Resources are estimated at 65 million m.t. of crude which would wash to 44 million m.t. of product grading 46.5% manganese. While there are a great many other manganese deposits and occurrences in Brazil, the Corumba and Carajas areas appear to offer the best opportunities for fulfilling the gap to be left by the ultimate depletion of Serra do Navio in 12-15 years.

3.6.3 Gabon

This country has a single group of deposits at Moanda, 575 km from the coast, with a present exit route through the People's Republic of Congo. The oxide deposits produce the highest metallurgical grade product in the world (presently 51.7% manganese). On a contained manganese basis, they rank second to South Africa in output, providing about 25% of the market economies' high-grade ore. The Moanda deposits also produce about 60% of the Western supply of high-grade manganese dioxide used for batteries and in chemical applications. Reserves would permit increased production of the various grades that are presently limited to about 2.7 million m.t. annually, the present capacity of the ropeway. Shipments could be increased to 4 million m.t. when the Transgabonese Railway is completed. Deposits are shallow and strippable. They have been investigated in close detail and are persistent and rather uniform. Estimation error is minimal and producer's reserve computations have been made on a recoverable yield basis that is more meaningful than on a crude ore basis.

Since the discovery in 1951, the vicinity and other areas further afield have been prospected for more oxide ore, but there has been no additional significant find. Resources of low-grade carbonate material are known to exist but have not been quantified because of lack of detailed exploration for carbonate protore.

3.6.4 India

India accounts for about 10% of market economies' production of metallurgical grade ore. In recent years India has become less important in world supply because of a production drop and its conservation measures that are reflected in the ban on exports of higher-grade ore (+45% manganese). A once-mechanized industry has reverted to intensive hand-labor operations at several small mines, for many of which little development of ore is done before mining. Little ore is in the measured category. A review by the Indian Geological Survey, with a view to self-sufficiency for an expanding alloy industry, shows that a considerable effort will be required to develop sufficient acceptable grade material for state industrial plans. Since reserves as given by the survey are divided by reliability category and identified with precision, and since the aggregate numbers are less than numbers carried as the inventory a decade ago, the quantities were accepted as reflecting the Indian Survey's critical assessment of the present position. Resources are poorly known but are expected to be scattered. Any significant future potential is expected to be underground, with attendant increases in production costs and a decline in grade. Highest-grade Indian ore is near outcrop and quality deteriorates both at depth and with increased metamorphism in various places.

3.6.5 Mexico

On a world scale, Mexico is a relatively small producer of manganese ore products. However, it has significant reserves and resources which could support a substantial increase in production if there is a market for the product. In 1978, Mexico produced about 3% of the world market countries' production, and provided the United States with about 8% of its ore imports and 5% of its ferromanganese imports.

Most production of manganese ore in Mexico comes from the Molango deposits that were discovered in 1960 by Compania Minera Autlan and placed in production in 1968. Scattered production from very small mines elsewhere in Mexico continues, but it is minor in comparison to Molango. The Molango deposits are located in the state of Hidalgo and are known over an area roughly 50 km north-south by 25 km east-west. The center of the area lies approximately 160 km north of Mexico City and 170 km west of Tampico, the shipping port for the ore and locally produced ferromanganese.

The manganese deposits occur in, or are associated with, an extensive unit of manganiferous limestone about 25 m thick. The manganese content ranges from 5% to 30% manganese, with the higher values near the base of the unit. The formation has been traced along a strike length of 50 km, but it is not continuous with respect to manganese content.

There are two types of manganese deposits. The most important is the fine-grained, thinly laminated, calcium-manganese carbonate rock that comprises the ore fed to the nodulizing kiln. The typical grade is 27.0% Mn, 7.1% Fe, 13.3% SiO_2, 2.5% Al_2O_3, 4.4% CaO, 4.4% MgO, 1.8% S, and 28.0% CO_2. The second type is rich oxide ore derived from the carbonate ores by oxidation and supergene enrichment. Reserves of oxide ore are limited, but the product is a valuable source of manganese suitable for dry-cell batteries.

Carbonate ore is mined by both open pit and underground methods. After beneficiation and nodulizing in a rotary kiln, the product, running 39% manganese and 10% iron, is trucked to Tampico for conversion in the ferroalloy plant there, or is shipped as nodules. Annual production is about 350 thousand m.t. of nodules per year, and plans call for doubling this rate of output in 1980 or 1981 with the completion of a second kiln.

Identified reserves of carbonate ore include 30.0 million m.t. at 26% manganese (measured and indicated) and 200 million m.t. at 25% manganese (inferred). The company (Cia. Minera Autlan) also estimates an additional resource of 1.3 billion m.t. at 25% manganese and of 14 billion m.t. at 10% manganese. Reserves of oxide ore are placed at 1.5 million m.t.

3.6.6 South Africa

The important deposits are in the Kalahari Basin (Kuruman), 960 km by rail from export ports. The deposits produce about 33% high-grade, 10% medium-grade, and the balance (57%) lower-grade material for blending in alloy production. South Africa accounts for about 35% of Western international supply on a contained manganese basis. Although a significant amount of ore is used for alloy production to satisfy local steel requirements and the export alloy market, the country is a very significant exporter of ores and concentrates. Having to ship long distances results in lower yield to the exporters because delivered cost must be competitive with sources close to Europe. Because of relatively cheap energy and efficient mechanized mining and thick beds permitting high productivity, present production is competitive in export markets even though only one mine (Mamatwan) out of the six important ones is openpit.

The Kuruman district has large reserves and resources and would be capable of increased production, although it should be noted that the higher-grade ore is only 30% of total reserves and about 3% of resources and reserves. The manganese-bearing material ranges in manganese content from 48% to as low as 20% manganese at depths from 20 m to 1000 m. Reserves are fairly well investigated by boreholes near existing mines. There has been a considerable extrapolation between widely spaced observation points away from production centers and the material is poorly identified in depth due to the high cost of drilling. In the tabulation, the segregation of material in the reserve and resource tables took account of the most recently published information available from South African mining companies, as well as earlier, subsequently unmodified, data. Also, a large amount of resource data was provided to the Minerals Bureau of South Africa by the leading mining company.

These data,* which are not qualified as to the profitability or feasibility of mining, were also reviewed and segregated by judgments as to reliability of projection, economics of mining, and utility of product. The indisputably economic acceptable grade of ore totals 886 million m.t. in situ (38-48% manganese), which is the largest reserve in the market economies. About 65% of the reserves are the Mamatwan-type calcareous ore, which has a somewhat restricted application in the electric-furnace production of alloys. Reserves resulting from additional investigation in the district have not been reported. The large totals for resources were divided between submarginal where cost vs. price, i.e., whether or not it is economical, is the ruling criterion, and hypothetical where a reasonable presumption of existence (without regard to economics) is the ruling criterion. It should be realized that material in the hypothetical category is reasonably expected to exist, but no more is known about it until observation points are more numerous. Lacking precise data, no material could be distinctly classified as paramarginal.

In addition to the panel's figure for identified reserves of 886 million m.t. of an indisputably, economically acceptable grade of ore in situ (38-48% manganese), another 10,197 million m.t. were classified in the resource category. Undoubtedly, as further drilling and development work progresses in both the Mamatwan and Wessels manganese fields, knowledge regarding the extent, continuity, and grade of the orebodies will be refined. The extent to which occurrences now classified as resources by the panel will be reclassified as reserve in the future will depend mainly upon the future relationship between cost of production and market price.

3.6.7 USSR

Reserves and resources were estimated using the most recent USSR publications and statistics, and applying rather low recovery factors where so indicated. About 83% of the economic USSR reserves are in the Nikopol' basin, South Ukraine, which produces 72% of the usable products. About 9% of the reserves are in the Caucasus, Georgian SSR Tchiatura region which produces 28% of the products, mainly better grade than Nikopol'. Other USSR production is insignificant and other "reserves" are economically marginal. These two important areas have been mined essentially since 1890. Although manganese investigations have been intensive under the socialist government in the last 50 years, and although new low-grade finds have been reported from Kazakhstan, Urals, and Western and Eastern Siberia at least 25 years ago, no new important manganese-producing centers have been developed. Tchiatura is in decline, and is estimated to last another 18 years at 1980 planned production rates. Salvage operations in previously mined workings, optimization of underground mining, and recovery of low-grade fine manganese from slimes are symptomatic of manganese conservation. A USSR symposium stated in 1973 that the decrease in reserves of rich oxide ores is becoming acute in long-worked deposits (Tchiatura and Nikopol').

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*See Part II for discussion of South Africa figures.

The Nikopol' open-pit operations mine very low-grade ore with extraordinarily large strip ratios and produce usable concentrates and sinter at high cost after considerable processing losses. High-strip open-pit ore is more costly than underground ore, but stripping has nevertheless been increased, suggesting manganese conservation. Open pits presently identified will fill All-Union requirements for 30 years from 1980.

The USSR is a declining factor in Western ore markets and centrally planned economy countries purchases of Western high-grade manganese ore have increased over the past decade from nil to half a million m.t. annually in 1980. The long-term self-sufficiency policy for the USSR would appear to use resource material that is difficult to beneficiate at still higher cost. Even so, centrally planned economy countries' Western manganese ore imports may be expected to increase. Zelony (1980) reviews Fine's (1980) recent presentation on increasing ore import and discloses that the bloc, including the USSR, last year imported 400,000 m.t. Next year imports could reach 500,000 to 700,000 m.t. of high-grade manganese ore.

Were production from a Western mine disrupted, removing say a million tons of contained manganese from supply, it is doubtful that Nikopol' could fill the gap. Nikopol' would require a 50% addition to its productive capacity, already complicated by the necessity of extensive earth-moving equipment. The USSR ore recognized as having practical significance has been well investigated, so major extensions are unlikely. As shown in Tables 3-7 and 3-8, 94% of USSR material is classified as a reserve in the two well-investigated districts of Nikopol' and Tchiatura. The remaining 6% of the material, i.e., the balance of inventoried resources is very small in comparison, is scattered and is thus unlikely to provide a base for further significant expansion.

3.6.8 Peoples Republic of China

The scattered deposits in aggregate appear to contain sufficient recoverable contained manganese to assure China's industrial needs, including planned steel expansion, into the 2020's. Little of the metallurgical ore is high grade, much is believed to have contaminants such as high phosphorus, and production is scattered from geographically dispersed centers, many in areas without good modern transport. It is concluded that unless there are important new discoveries and rationalization of the production, China cannot be a significant factor in international manganese supply.

There is geological potential for as yet undiscovered marine sedimentary carbonate manganese ores of the large reserve/resource type. The assessment of this potential by Chinese geologists has not been completed.

3.6.9 World Resources

In Table 3-8 little resource is shown for the USSR because what would be considered submarginal material in the free-market economies is being worked in spite of grade. The largest submarginal resources tabulated are in the Republic of South Africa.

Bulgaria and Mexico appear with previously unreported large figures for hypothetical resources. It should be stressed that in the USGS/BOM terminology, the qualifying "hypothetical" associated with resources refers to the reliability of the projection rather than to the economics. In the cases of both Mexico and Bulgaria, the projection is made over tens of kilometers between observation points. While it is reasonable that there is legitimate extrapolation, in view of the geological occurrence the reader should be aware that there is also a chance that part of the material does not exist. Because both of these resources are largely underground and of exceedingly low grade, they do not appear to be a likely source of manganese units for a considerable period of time, if ever. The hypothetical, large resource which may eventually become economic under better conditions than in Bulgaria or Mexico is in South Africa.

REFERENCES

Bureau of Mines, Minerals Yearbook, Vol. 1, pp. 617-628, 1977.

Chernyshev, G.B. "Evaluation of Manganese Ore Deposits During Exploration and Detail Prospecting." In Manganese Deposits of the Soviet Union (Margantsevye mestorozhdeniya SSSR Izdatel'stvo "Nauka", Moscow), Israel Program for Scientific Translations, transl. Rosenthal, E. Jerusalem: Meter Press, 1967.

Dorr, J.V.N., II, Crittenden, M.D., Jr., and Worl, R.G. Manganese. Professional Paper 820, U.S. Mineral Resources. U.S. Geological Survey, Washington, D.C., pp. 385-399, U.S. Government Printing Office, 1973.

Featherstone, R.A. Applications of Mamatwan Ore. Proceedings of Infacon 1974, The First International Congress on Ferro-Alloys, 22-26 April 1974, S. African Inst. of Min. and Metall., Johannesburg, 1974.

Hooper, R.T. The Production of Ferromanganese, Journal of Metals Vol. 20, pp. 88-92, 1968.

Hooper, R.T. Racionalizacion de la Industria de Ferroaleaciones de Australia (The Australian Ferroalloy Industry Rationalized), Prococeedings ILAFA-Ferroalloys Congress, Acapulco, Mexico, May 14-18, 1978, pp. 111-120, 1978

Kuzvart, M. and Bohmer, M. Prospecting and Exploration of Mineral Deposits, Transl. H. Zarubova, Elsevier Scientific Publishing Company, Amsterdam, 1978.

Park, C.F., Jr. On the Origin of Manganese, Symposium on Manganese, Volume I, International Geological Congress, Mexico City, Mexico, 1956.

Roy, S., Classification of Manganese Deposits, Acta Mineral. Petrogr. 19, pp. 67-83, 1969

Roy, S, Ancient Manganese Deposits, Handbook on Strata-Bound and Stratiform Deposits, K.H. Wolf, ed., Elsevier Scientific Publishing Company, Amsterdam, 1976.

Streicher, P.F., The Manganese Market and Its Outlook for the Future from a South African Point of View, European Economic Community Roundtable, Dec. 4-5, 1979. Brussels, Preprint 1979.

U.S. Geological Survey, Principles of Mineral Resource Classification Systems of the U.S. Bureau of Mines and the U.S. Geological Survey, USGS Bulleing 1450-A, U. S. Government Printing Office, 1976.

Varentsov, I.M., Sedimentary Manganese Ores, Elsevier Scientific Publishing Company, Amsterdam, 1964.

Weiss, S.A., Manganese -- The Other Uses, Metal Bulletin Books Ltd., Letchworth, Garden City Press Ltd., 1977.

Zelony, S., Russia's Sudden Reach for Raw Materials, [Fine, D.I. presentation to the World Affair's Council, July 9, 1980, Mineral Resource Dependency Crisis: Soviet Union and the United States] Fortune, pp. 43-44, July 28, 1980.

Chapter 4

DEEP-SEABED NODULES

The charge to the panel was to evaluate the land-based reserves and resources of manganese. Therefore, a detailed examination of the seabed nodules is outside the scope of this inquiry. However, the panel felt that for completeness a short review of the status of this important resource should be included in the report. Similar land-based nodule beds in Chamberlain, South Dakota have been noted in this report (Section B.3, p. 267, Table B-1 and p. 269) but are not discussed in this report because of their relatively low importance to the total manganese supply picture. NMAB Report 323 (1976) evaluates the potential of these and other U.S. deposits.

Manganese nodules on the deep sea floor first were discovered in the 1870's by the British research vessel H.M.S. Challenger. Interest in nodules as sources of metals did not develop until the 1950's. Since the mid-1960's several groups of companies have spent hundreds of millions of dollars for seabed exploration, mainly in the North Pacific, and for research into systems for recovering and processing the nodules. Cobalt, copper, and nickel currently are the metals of major economic importance in the nodules, although manganese, the major metallic constituent, and other metal elements may be recovered as well.

4.1 CONSORTIA

Five major consortia, four of which include U.S. firms, have engaged in this work: Ocean Mining Associates, Ocean Management, Inc., Ocean Minerals Company, the Kennecott joint venture, and the French group. An additional consortium, which includes members of some of the others, has concentrated on the development of a continuous line bucket (CLB) mining system. Some consortia are still engaged in research and exploration, while others have suspended operations.

4.2 OCEAN RESOURCES

Before the magnitude of the resources of the deep seabed can be discussed, the requirements of an ocean-mining operation must be reviewed. Because almost all deep-sea nodules are found at the interface between the water and seafloor, the resource is essentially two-dimensional rather than three-dimensional as are landbased metal deposits. Three characteristics are of major importance in determining the economic value of a nodule deposit: abundance, concentration, and grade.

4.2.1 Mine Site Requirements

Abundance is simply the percentage of the sea floor covered with nodules, while concentration is the mass of nodules per unit area. If nodules all were of the same size and density, abundance would be equivalent to concentration; because they are not, abundance can only be used to approximate concentration, given knowledge of size and density. Kaufman has stated that the average concentration needed to mine a nodule deposit is 10 kg/m^2 (2.0 lb/ft^2), with a cutoff concentration of 5 kg/m^2 (1 lb/ft^2) (Kaufman, 1974). Later writers on the subject generally have agreed with this assessment. These concentrations are wet weights; the dry weight is about 70% of the wet weight.

The minimum and average grades required of nodules have been subject to discussion. Kaufman (1974) suggests a cutoff grade of 1.0% nickel, 0.8% copper and 0.2% cobalt, on a dry basis. Archer (1976), Holser (1976), Kildow, et al. (1976), and Frazer (1977) have suggested average and cutoff grades of about 2.25 and 1.8% for nickel plus copper.

4.2.2 Nodule Mining Efficiencies

Of course, not all of the nodules on the seabed, even in a potentially rich mine site, can be recovered. Three factors important in determining nodule mining efficiencies are dredge efficiency, sweep efficiency, and terrain. The dredge head will not be able to pick up all the nodules in its path; some are likely to be swept under the dredge head or to the side, and some may simply fail to enter the pipe string. Kaufman (1974) feels that dredge efficiencies ultimately may reach 60%, but initially they will be lower.

Certain problems undoubtedly will be encountered in controlling the dredge head at depths of three miles. Gaps are likely to be left between adjacent passes of the dredge head, so not all nodules will be exposed to the dredge. Kaufman (1974) has stated that a sweep efficiency of 65% probably is the best that can be expected. The terrain of the sea floor is also important in determining nodule recoveries. Boulders, rock walls, outcrops of bedrock, and so forth are all obstructions that will hinder mining operations in many areas. Kaufman (1974) has estimated that 20 to 25% of any mine site may be inaccessible due to such obstructions.

Taking these factors together, at most about 30% of the nodules in a seabed deposit will be recoverable. For first generation technology, overall mining efficiencies are likely to be closer to 20%.

4.2.3 Potential Mine Sites

A number of researchers have developed estimates of the total area of the sea floor that will be suitable for ocean mining. Dividing this area by the area required for a single mine site yields an estimate of the total number of potential mine sites in the ocean. An area of above 50,000 km^2 will be required for a first generation operation that recovers 3 million dry m.t. of nodules annually for 25 years.

The most recent mine site estimates have used more sophisticated methods, applied to more extensive data, than did early estimates. Frazer (1977), Pasho and McIntosh (1976), and McKelvey, Wright and Rowland (1978) all estimate that about 26 first-generation mine sites might exist in the prime area in the Northeast Equatorial Pacific, the Clarion-Clipperton zone. The rest of the world's oceans seem less conducive to the formation of plentiful, high-grade nodules. Fewer first-generation mine sites are likely to be outside the Clarion-Clipperton area than in it. However, the uncertainties associated with these estimates are even greater than those for the Clarion-Clipperton area.

4.2.4 Seabed Manganese Resources

The mine site estimates discussed above imply that, at an average manganese content of 25%, potential first-generation mine sites in the Clarion-Clipperton area contain approximately 500 million m.t. of minable manganese. Approximately 2,500 million m.t. of manganese are estimated to be in the Clarion-Clipperton area, but a mining efficiency of only 20% limits the recoverable resource to only 500 million m.t. Total resources in all other areas of the oceans are likely to be smaller.

In the future, improvements in the technology for mining and processing manganese nodules will lead to upward revisions in estimates of available manganese. Sweep and dredge-head efficiencies will likely improve and innovations in processing will permit the use of lower grade nodules. No reliable estimates have been made of the manganese that will be minable when these technological improvements come about.

4.3 TECHNOLOGY

The technology required for mining and processing manganese nodules has been under development for over 10 years, but further research still is required. Two major mining approaches have been studied: dredges attached to pipe strings and continuous line buckets (CLB) system. Either relatively standard bulk vessels or slurry tankers will be used to transport the nodules to shore for processing; processing at sea currently appears highly unlikely. Either pyrometallurgical or hydrometallurgical processes might be used to recover metals, not necessarily including manganese, from the nodules.

4.3.1 Mining Systems

Two related dredge systems have been studied. Both include nodule collection devices that are guided by a mining vessel across the sea floor at the end of a three- to five-mile-long pipe string. One uses conventional pumps, the other an airlift system. The hydraulic system relies on submerged, multistaged pumps to force a slurry of nodules and sea water to the surface. In the airlift system air is injected into the pipe string at different levels, decreasing pressure in the upper part of the pipe string and drawing the nodule-sea water slurry to the surface. The CLB system involves buckets attached to a six-to-ten mile length of rope that is dragged across the sea floor. It has not yet been proved practical.

4.3.2 Processing

Either hydrometallurgical or pyrometallurgical processes could be used to recover nickel, copper, cobalt, and possibly manganese, from the nodules. The reasons why manganese might not be recovered from the nodules are both varied and complex. A 25% manganese ore is relatively low-grade and the processing required to extract the other metals can complicate manganese recovery. Furthermore, a single mining operation of 3 million dry m.t. of nodules could produce 600,000 m.t. of manganese annually if 80% of the manganese in the nodules can be recovered. Two such operations could more than satisfy all current U.S. metallurgical demands for manganese. This means that an ocean-mining consortium must be concerned about finding a market for all the manganese that it can produce.

Three factors favor manganese recovery. First, if manganese is recovered, the solid waste that might be disposed of is reduced by about one-fourth. Second, at the processing plant, the manganese will be contained in slags or residues of at least moderate grade. In essence, mining costs can be charged against the recovery of the other three metals, so the revenues from manganese recovery simply must cover the incremental capital and operating costs for recovery. Third, manganese-rich solid waste would require more treatment prior to disposal than would manganese-depleted material.

4.4 POLITICAL AND LEGAL ISSUES

One of the major obstacles faced by those wishing to mine the deep seabed is the unsettled legal status of ocean mining. Under historical interpretations of the law of the sea, the deep seabed can be mined by anyone wishing to do so. However, the United Nations Conference on the Law of the Sea (UNCLOS) has been meeting in several formal or informal sessions annually since 1973 to discuss deep-seabed mining and other issues concerning the oceans. The United Nations General Assembly has passed two resolutions on ocean mining, neither with the force of international law. The first, which the United States favored, declared that the mineral resources of the sea are "the common heritage of mankind." The second, which the United States opposed, called for a moratorium on ocean mining until a new law-of-the-sea treaty could be signed. Some of the legal and political obstacles faced by the ocean-mining industry must be resolved before any consortium will invest the $1 billion or more (1980 dollars) needed to develop a mine site, to perfect a mining system, and to build a processing plant.

4.5 FUTURE OCEAN MINING

Ocean mining probably is still at least 10 years away. Last year (June 28, 1980) the United States on its own initiative passed legislation to facilitate ocean mining by companies incorporated in the United States. This overcomes at least the immediate political obstacles hampering ocean mining. It also may enable the companies involved to raise the capital required for an investment of over $1 billion (in 1980 dollars). Technical and environmental problems, the latter under study by the National Oceanic and Atmospheric Administration, should take another few years to resolve. However, the environmental problems, at least at sea, currently do not seem severe.

REFERENCES

Archer, A.A., The Prospects for the Exploitation of Manganese Nodules, the Main Technical, Economic and Legal Problems, Paper presented at CCOP/SOPAC-IOC/IDOE International Scientific Workshop on the Geology, Mineral Resources and Geophysics of the South Pacific, Institute of Geological Sciences, London, 1976.

Frazer, J.Z., Manganese Nodule Reserves: An Updated Estimate, Marine Mining 1, 1/2, pp. 102-103, 1977.

Holser, A.F., Manganese Nodule Resources and Mine Site Availability, Professional Staff Study, Ocean Mining Administration, U.S. Department of the Interior, U.S. Government Printing Office, Washington, D. C., 1976.

Kaufman, R., The Selection and Sizing of Tracts Comprising a Manganese Nodule Ore Body, Paper presented at the Sixth Annual Offshore Technology Conference, Houston,1974.

Kildow, J.T., Bever, M.B., Dar, V.K., and Capstaff, A.E., Assessment of Economic and Regulatory Conditions Affecting Ocean Minerals Resource Development, report prepared by the Massachusetts Institute of Technology for the U.S. Department of the Interior, Bureau of Mines, Open File Report 89-78, 1976.

McKelvey, V.E., Wright, N.A., and Rowland, R.W, Manganese Nodule Resources in the Northeastern Equatorial Pacific, U.S. Geological Survey, Open File Report 78-814, August 1978.

Panel on Manganese Recovery Technology, Manganese Recovery Technology, NMAB-323, 1976.

Pasho, D.W., Review of the Development of Deep Seabed Manganese Nodules, The Northern Miner, B6, B9, B13, April 14, 1977.

Pasho, D.W. and McIntosh, J.A., Recoverable Nickel and Copper from Manganese Nodules in the Northeast Equatorial Pacific--Preliminary Results, Canadian Institute of Mining and Metallurgy Bulletin, September 1976.

Public Law 96-283. (H.R. 2759), Deep Seabed Hard Mineral Resources Act, 30 USC 1401 note, June 28, 1980.

CHAPTER 5

MINING AND METALLURGY*

This portion of the study considers technological changes that might influence the amount of manganese classified as reserves. Certain present practices are indeed affecting later recovery of material left in the ground. In most instances pillars left for support in room and pillar mining may be considered as lost resources since future recovery is difficult, if not impossible, unless provision to backfill the mined areas has been made. On the other hand, fine material left from the sizing of manganese ores and stockpiled on the surface is available for processing into usable products. As treatment methods are developed or improved, the comparative cost of mining new material exceeds the expense of processing. Thus, the acceptability of the product from fines becomes more attractive.

Classification of larger amounts of manganese ore as reserves could arise from improved technological developments in mining and processing. However, a review of currently developing technology does not indicate an early breakthrough in either mining or processing methods that would add significant quantities under present or near-future economics. Application of proven and developed procedures will allow for cost-effective utilization of the better manganese resources. Continued research and investigation of improved recovery methods will be encouraged by the depletion of the large, high-grade surface deposits. Manganese will remain as an essential ingredient in steelmaking, with no practical substitute in sight.

Worldwide demand for manganese for steelmaking will fluctuate with the production of steel. Conservation of manganese in steelmaking is possible, but because of economic reasons is likely to receive only modest effort by steelmakers. Foreseeable changes in mining, processing, and steelmaking technology are likely to have only minor effects, if any, on the manganese deposits that are classified as reserves.

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*See Glossary for explanation of many terms used in this chapter.

5.1 MINING

Ore recovered from developed manganese reserves probably will be no greater than that amount which will yield the maximum economic return for the particular deposit being worked, exclusive of any self-sufficiency criterion that might be applied. Deposits mined by open-pit will continue to return the highest recovery per ton of ore in the reserve. However, as the extraction of ore by open-pit becomes uneconomical because of excessive overburden, extending the open-pits into underground operations probably will cost less than developing new open-pit mines. The declining availability of large, new near-surface, high-grade deposits and the lack of new open-pit mining technology will further encourage the application of underground mining methods to the deep extensions of open-pits containing reserves of the types most desired. The shift from open-pit mining to more underground operations will result in lower ore recoveries, considerably higher costs and lower production output.

5.1.1 Open-Pit Mining

A substantial portion of the present world production of high-grade manganese ore comes from mines developed by open-pit technology. Selected individual examples noted here are: Australia--Groote Eylandt; Brazil--Serra do Navio; Gabon--Moanda; Ghana--Nsuta; and South Africa--Mamatwan. Production from these mines accounted for about three-fourths of the manganese produced in the non-centrally planned economy countries during the past several years.

Effective open-pit mining operations are dependent on a variety of factors and circumstances, usually of natural origin and beyond the developer's control. Important among these are the geometric dimensions of the ore occurrence, ore-to-waste boundaries, required slope of benches, attitude of the mineral deposit and adjacent ground, and size and volume of the ore section. Modern pit-planning techniques have improved the operation in a wide range of mines, extracting various metals, around the world. Application of these same practices to open-pit manganese mines has been limited due to a variety of reasons; e.g., bedded nature of manganese deposits, attitude of these beds, thickness of the individual ore horizons, the limited tonnages. Continued successful production relies on the proven performance of the rotary drill, diesel and electric shovel, and off-highway truck.

Serious consideration is being given to energy conservation in the mining processes and ore and waste transportation. Conveyor haulage is being substituted for truck transportation where feasible. This change is supported by the following advantages: less sensitivity to cost inflation; lower maintenance requirements; lower energy and labor requirements; and independence from diesel fuel availability.

Regardless of the modifications made to equipment and manpower, most open-pit mines will reach a point where the amount of waste removed per ton of ore prohibits continued economic operation. At this point, a move to underground mining may be indicated, if mineralization continues at depth and the quality of the material to be mined is adequate to support the increased cost.

5.1.2 Underground Mining

Underground mining in the non-centrally planned economy countries is expected to expand as the large, open-pit, high-grade deposits approach depletion. Considerable attention no doubt will be given to increased recovery from developed mines and the application of new, effective methods of underground extraction. Selected individual mines now operating underground are noted here: South Africa--Farm Wessels, Middelplaats, Black Rock; India--Balapur Hameska; and Morocco--Imini.

The underground mining method selected will depend a great deal on the characteristics of each individual ore occurrence. Evaluation of the problem of fines and ore dilution should be resolved early in the exploitation of each deposit. Application of block-caving techniques may be feasible where surface disturbance already is pronounced. Down-dip extensions of ore mined by open-pit methods could be extracted by underground development using room and pillar (with either ore support or artificial support allowing removal of pillars), modified cut and fill, longwall variations, or a combination of these with load-haul-dump (LHD) adaptations.

Room and Pillar -- Application of LHD equipment to this method of extraction no doubt will continue because of its adaptability to conform to the irregularities of the ore body. Recovery of the pillars should become more attractive and methods for pillar removal will be developed. Artificial support rather than natural support will be practical in some instances. Vertical cement-filled boreholes through the ore at predetermined intervals may serve as one means of support. Pit-prop assemblies may prove feasible in the narrower seams. Some application of both rock and hydraulic fill systems may be practical. Reduction in the loss to pillars could increase recovery by 10 to 30%. Many times the need for large pillar areas is required not only by the lack of competency* of the roof but also by the weakness of the ore left for support.

The most recent large underground mine to come into production in South Africa (Middelplaats) demonstrates the effects on mining of the complex nature of the ore deposits. Initially, rooms and cross-cuts will be mined 6 m wide leaving pillars 6 m by 6 m as support. Preliminary plans call for a 75% overall mining recovery. Pillar extraction apparently is not economically viable during the 30 years of projected life of this mine. The quality of the deposit has a strong influence over the practicality of using other than natural ore pillars for support. A 45-48% manganese content could possibly have justified the added cost of secondary roof support.

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*See Glossary.

Longwall Methods--Application of longwall techniques will continue to be extremely restricted because of the irregular nature of the manganese occurrences. Certain adaptations of this method of extraction may provide acceptable results when applied to narrow, high-grade, and generally uniform deposits. The use of continuous miners, which are effective in the extraction of coal seams, may prove feasible in these regular occurrences. The use of these machines when applied to the more resistant manganese mineralization awaits development of a satisfactory cutter assembly. A production-scale operation, testing the practicality of combining continuous miners and pit-prop assemblies and/or packwalls with longwall procedures, on phosphate deposits could provide a starting point in the development of this practice. Because a good deal of analysis would be required on each deposit considered for exploitation by this procedure, early successful application should not be anticipated.

Modifications of Cut-and-Fill--Application of variations of cut-and-fill methods may be feasible, in some instances, using load-haul-dump (LHD) equipment and mined fill. In the processing of the ore mined, there is no strictly waste (tailings) material to be used, as in most currently operating mines using this technique. When available, classified desert sands could be used effectively. Cement would also certainly be required in the use of most natural sands, thus increasing costs and requiring additional preparation steps.

5.1.3 Technical Developments

Technical developments that might increase the reserves of a given resource are limited. This appears to be influenced by the economics of applying presently available methods of extraction and the cost and implementation requirements for using new developments. Equipment allowing deeper mining by open-pit methods is available and improvements are progressing steadily. However, the application of these advances to the rather limited tonnages associated with manganese mining seem limited. Increased recoverability could be achieved by presently available technology, but the cost would be higher.

In summary, the application of these new and different mining practices could increase reserves of most deposits using underground methods, if increased mining costs are acceptable.

5.1.4 Relative Costs

Figures 5-1 and 5-2 depict the trend to higher costs when converting from open-pit to underground mining. Figure 5-1 shows the increased unit cost of mining in an underground extension of a previously mined open pit as compared to the cost of open-pit mining at different waste-to-ore stripping ratios. The unit cost reference is based on a waste-to-ore open-pit stripping ratio of 4 to 1.

Open-pit operating and capital costs increase significantly as the waste-to-ore stripping ratios increase. With a 6 to 1 stripping ratio the unit cost is 1.4 times that at a 4 to 1 stripping ratio; at an 8 to 1 ratio the cost is about 1.8 times greater. At a 5.5 to 1 strip ratio open-pit and underground operating and capital costs are about the same but ore recovery by underground mining is only 80 percent if the recovery for open-pit operations is considered to be 100 percent. Improving the ore recovery by installing temporary or permanent roof support systems is costly. Thus, to achieve a 95-percent ore recovery by underground mining incurs a unit cost almost 1.6 times the unit cost of open-pit mining. As shown in Figure 5-2, the mining operating cost differentials between open-pit and underground mining follow the same patterns as those in Figure 5-1, except that they are slightly smaller.

The increased mining cost with depth of underground operations is shown in Figure 5-3. Down to a depth of about 500 to 600 meters, the total operating and capital cost of mining gradually increases and beyond these depths the costs become disproportionately greater.

The data shown in the three tables undeniably illustrate that substantially increased costs will be incurred in converting from open-pit to underground mining as open-pit operations become impractical with depth. The data also strongly indicate that converting from open-pit to underground mining will result in lower ore recoveries than are achieved by current open-pit operations. Considering the higher production costs and lower ore recoveries, the price of manganese ore can be expected to increase markedly as more underground mining is undertaken. Although more and more production can be expected to come from underground mining as surface mining declines, this will not necessarily increase the manganese reserve base.

5.2 PROCESSING OF ORE

The increased demand for manganese ores and the depletion of some high-grade deposits to support the high level of industrial activity over the years have led to the mining of lower-grade materials and the increased use of beneficiation to provide acceptable products to the customer.

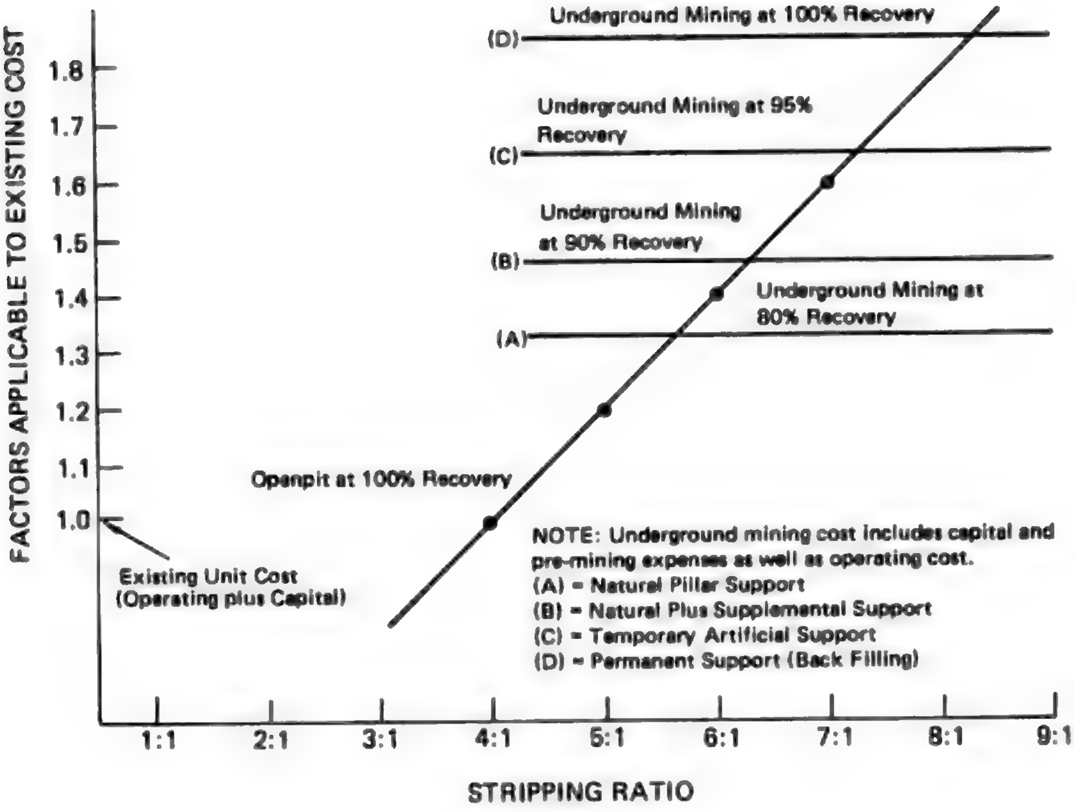

FIGURE 5-1. Mining Capital, Development and Operating Cost Comparisons for First-Interval Mining Beyond the Open-pit Phase

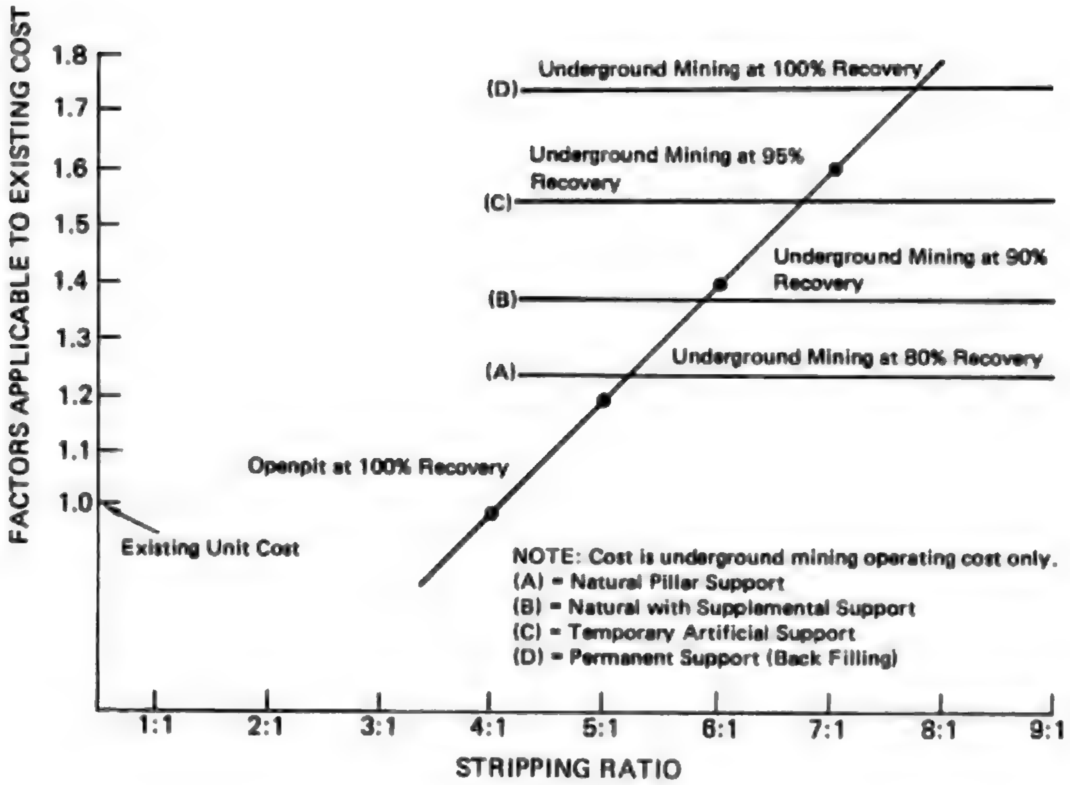

FIGURE 5-2. Mining Operating Cost Comparisons for First-Interval Mining Beyond Open-pit Phase

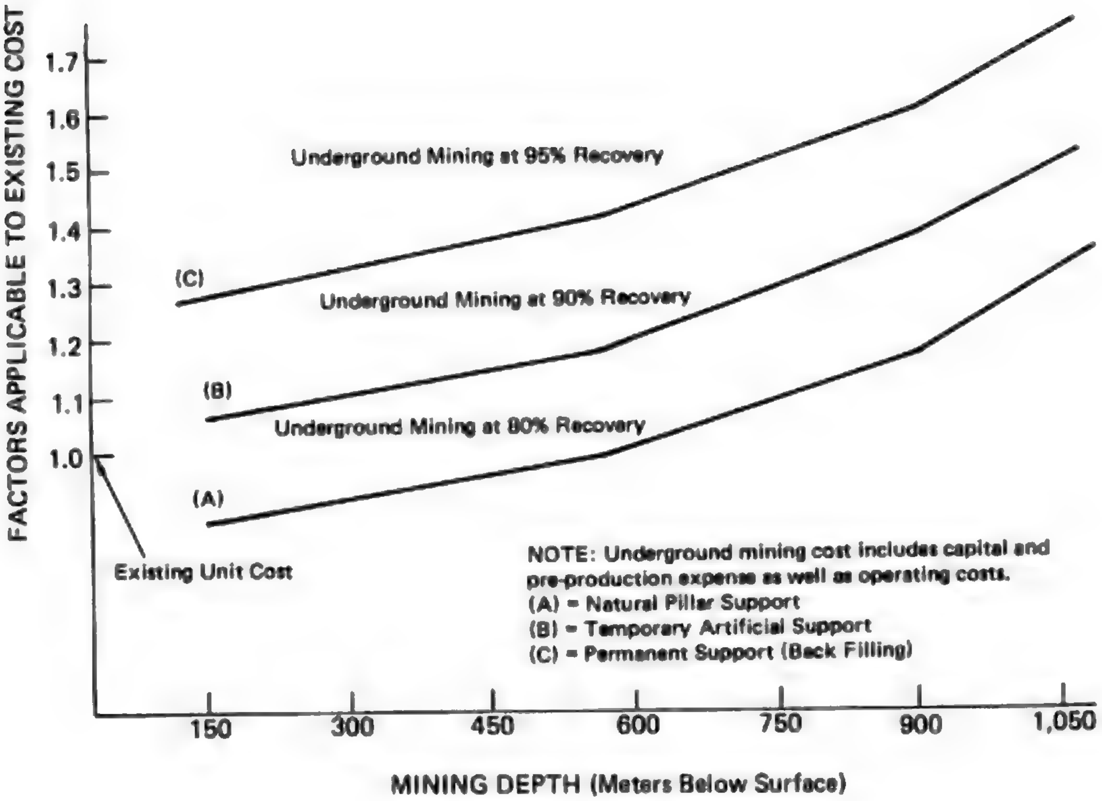

FIGURE 5-3. Mining Cost Related to Depth of the Mine, Including Total Operating and Capital Costs

Situations where beneficiation will continue to prove both necessary and rewarding include:

1) Utilization of fines from the crushing, washing, and screening activities associated with most manganese ore production;

2) Utilization of the lower-quality material that occurs within and adjacent to higher-grade deposits; and

3) Utilization of subgrade individual deposits not suitable for use without upgrading.

The beneficiation of the various materials cited above and the selection of the process used will depend on the characteristics of each ore, the location of the deposit, and the relative economics of processing versus development of additional ore of specification grade, if available. Most certainly, the application of processing steps, most of which are energy intensive, will be restricted by competitive economic realities.

5.2.1 Physical Beneficiation

The simplest and least expensive means of improving the oxide product quality are the physical methods. These depend on the natural characteristics of the mined ore to effect a separation of the higher-quality material from the gangue or lower-quality portion.

Screening and washing, usually following a crushing step, are the simplest and most widely used processes. In earlier exploitation of the higher-grade deposits, use of this procedure resulted in the production of fines that were "reserved" for some future utilization when both the need and the available technology would provide an economic climate favorable to such activity. The higher-quality fines require only agglomeration to provide a satisfactory product. Pelletizing, briquetting, and compaction are mechanical processes using binders with the application of energy to combine the fine materials into stable shapes of a size acceptable for end-use processes. Where the quality of the fines does not satisfy that required for industrial applications, a variety of processes dependent on the physical characteristics of the ore are available.

Sink-float is a method by which the better quality material is separated from that of poorer character by use of a separating medium having a specific gravity that allows for the sinking of the heavier particles and the floating of the lighter materials. Recoveries of fines are usually not high, and the resultant product quality is only slightly higher than it was initially. Certain ores respond favorably to this process so that a product meeting chemical specification results. However, when treating the fine fractions, it is often necessary to follow this phase with an additional step to attain size specifications.

An alternate method of treating subquality products is by magnetic separation, where the magnetic susceptibility of the various minerals to high-intensity magnetic attraction will allow the separation of the better material into an acceptable product. Here, again, the additional step to meet size specifications is required.

Off-grade materials may also respond to treatment by one of the more complex and costly techniques described below.

5.2.2 Flotation and Hydrometallurgical Processing

Lower-quality ores, fines, and complex fine-grained ores not readily amenable to the simpler, less costly methods described earlier could be processed by flotation, which requires the grinding of the material to be treated to effect liberation of the manganese minerals from the gangue (waste) constituents of the ore. Once freed from physical combination, the various minerals may be separated by producing a froth. This is done through the use of organic reagents in a liquid pulp with controlled alkalinity, along with the introduction of air and agitation. Certain minerals are coated with bubbles and float to the surface where they are skimmed off. Either the gangue or the manganese mineral could be the float product, depending on the mineral composition and the selection of reagents and operating conditions. This product, because of the water present, must be thickened, filtered, and agglomerated by one of the methods above, or by application of a pyrometallurgical process such as sintering or nodulizing. This is particularly true of ores with manganese carbonate mineralization.

Hydrometallurgic processes involve the chemical solution of the manganese from the minerals present. In the case of certain oxide minerals of manganese, a preliminary pyrometallurgical step (sintering or roasting) is required to improve the solubility of manganese in the next step. After purification of this solution, the manganese is recovered by a variety of methods. Among these procedures are crystallization and/or precipitation, followed in some cases by calcining and some form of agglomeration such as nodulizing or sintering. Electrolytic methods are applied to certain of the purified manganese solutions to produce manganese metal or synthetic manganese dioxide. Most of the individual steps in the various hydrometallurgical processes are energy-intensive, have corrosion-related operating problems, and significant pollution-control requirements. These circumstances result in a serious economic handicap when competing for markets presently being supplied by natural, high-grade ores.

5.2.3 Pyrometallurgical Beneficiation

Nodulizing, pelletizing, and sintering are used in the preparation of natural ores or fines as feeds to ferromanganese and silicomanganese furnaces. All are pyrometallurgical processes, where the application of energy is in the form of heat either from combustion of hydrocarbons or by electricity. Manganese carbonate products, when subjected to sintering or nodulizing or pelletizing are upgraded by the elimination of carbon dioxide and the resulting agglomerated product provides a satisfactory feed to either blast or electric furnaces. Economical uses of pyrometallurgical processes are restricted to the higher-grade products that require either agglomeration or a combination of upgrading and agglomeration to meet industry specifications. More complex multistage pyrometallurgical processes have been adapted to the processing of manganese ores. However, the cost of these processes, especially in view of the escalation in energy costs in recent times, continues to be prohibitive in most cases.

5.2.4 Continued Research

Except in Russia where self-sufficiency is paramount, continued research into practical methods of beneficiation is limited by the lack of immediate need. Adequate world supplies of good-quality ores are available from existing and developing mines. However, a realistic forward look reveals that available new sources of good-quality ore will become nonexistent. Under such circumstances the integration of more sophisticated beneficiation plants with the mining complex will become the rule rather than the exception. Currently, several of the major manganese producers are either designing or building processing facilities to treat fines, lower-grade ores, or ores with a mineral composition not compatible with existing market requirements.

5.3 CONVERSION OF ORE TO METALLIC ALLOYS

The upgraded forms into which manganese ore is converted for use in steelmaking consist of several manganese ferroalloys and electrolytic manganese metal. For purposes of this study, attention can be confined to the three chief alloy products: standard high-carbon ferromanganese, silicomanganese, and medium-carbon ferromanganese. Typical manganese, carbon, and silicon contents of these ferro-alloys are given in Table 5-1. As shown in Table 5-2, standard high-carbon ferromanganese is universally the manganese ferro-alloy most frequently used in steelmaking. In the United States, usage of standard high-carbon ferromanganese is four to five times as great as usage of either silicomanganese or combined medium- plus low-carbon ferromanganese.

Smelting of manganese ore to standard high-carbon ferromanganese can be carried out in either a blast furnace or an electric submerged-arc furnace. Silicomanganese, medium-carbon ferromanganese, and low-carbon ferromanganese are produced by means of electric furnace processing. Some low-carbon ferromanganese is also produced by fused-salt electrolysis. Figure 5-4 is a schematic diagram of various routes by which manganese products can be obtained, starting from manganese ore as raw material. Smelting practices and processing options in ferromanganese manufacture were summarized in a previous study (National Materials Advisory Board, 1976, p. 25) as follows:

TABLE 5-1. TYPICAL ANALYSES OF FERROMANGANESE PRODUCT FAMILY (PERCENT)

	Manganese	Carbon	Silicon
Standard high-carbon ferromanganese	79	6.8	0.5
Silicomanganese	67	1.8	17.0
Medium-carbon ferromanganese	82	1.3	0.5

SOURCE: Borden, presentation to the panel, 1979.

TABLE 5-2. MANGANESE ADDITION ALLOYS AS PERCENT OF TOTAL MANGANESE USED BY EACH COUNTRY

	1978			1984		
Geographic Region	Std Fe Mn	MC & LC	Si Mn	Std Fe Mn	MC & LC	Si Mn
United States	70.5	13.5	16.0	70.0	14.0	16.0
Canada	74.9	12.1	13.0	71.5	13.9	14.6
Western Europe	75.1	11.8	13.1	72.0	13.2	14.8
Japan	52.5	11.8	35.7	51.5	13.0	35.5
Latin America	80.1	9.8	10.1	77.1	11.1	11.8
Africa/Mideast	80.1	10.0	9.9	77.0	11.1	11.9
Other Asia	80.1	10.0	9.9	77.0	11.1	11.9
Western World-Total	69.7	12.0	18.3	68.1	12.9	19.0

SOURCE: Presentation to the panel, Borden, 1979.

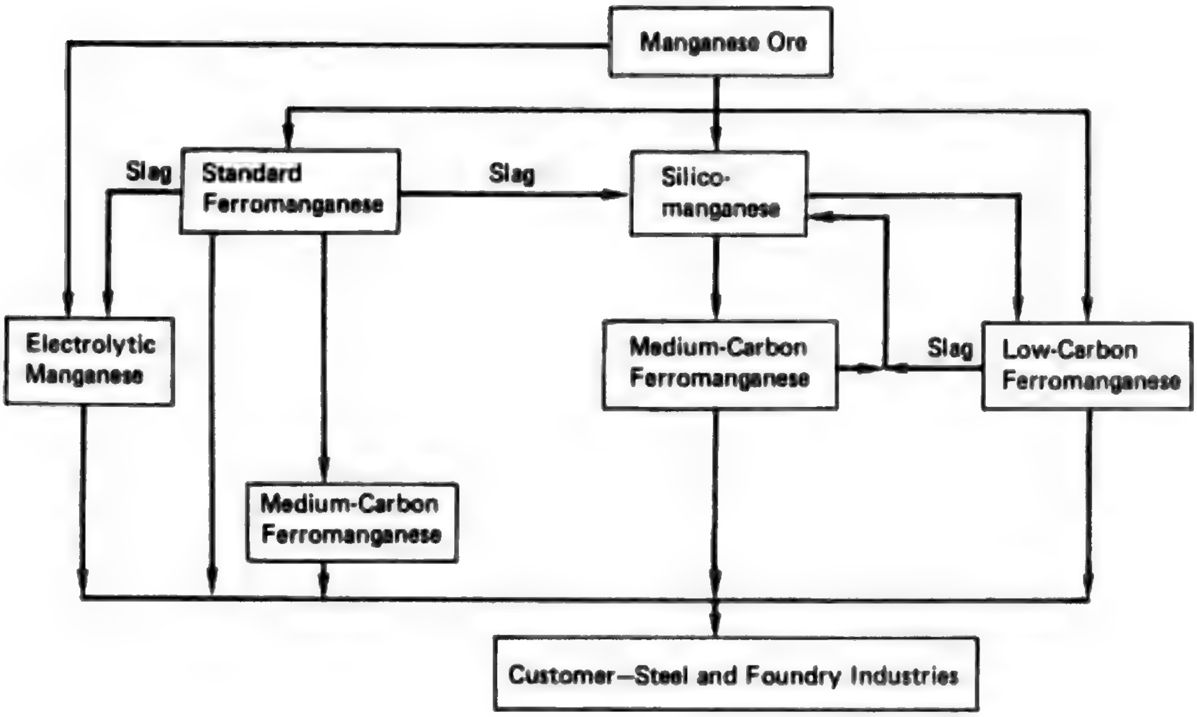
Manganese Ore
Slag
Standard Ferromanganese
Slag
Silico-manganese
Electrolytic Manganese
Medium-Carbon Ferromanganese
Slag
Low-Carbon Ferromanganese
Medium-Carbon Ferromanganese
Customer—Steel and Foundry Industries

FIGURE 5-4. Production Routes of Manganese Alloys (Borden, presentation to the panel, 1979)

Standard ferromanganese is produced by either of two smelting procedures depending on the smelting facilities available, the gangue constituents of the ore, and whether silicomanganese is to be produced as well as several grades of ferromanganese. If silicomanganese is not to be produced, the ore is smelted with large amounts of basic flux (lime or magnesia or both) in an electric or blast furnace to yield ferromanganese and a discardable slag containing 10 to 20 percent manganese; manganese recovery in the ferromanganese is about 80 percent. If silicomanganese is to be produced, the ore is smelted with little or no flux in an electric furnace to yield ferromanganese and a nearly neutral slag containing 30 to 40 percent manganese. The slag is resmelted in an electric furnace to produce silicomanganese. Overall manganese recovery in this two-step process is more than 90 percent.

The blast furnaces used generally have been old pig-iron furnaces adapted for ferromanganese production, and productivity ranges up to about 220,000 short tons of ferromanganese per year per furnace. The electric furnaces range from 2,000 kW to 30,000 kW in power capacity and productivity ranges up to 130,000 tons of ferromanganese or 90,000 tons of silicomanganese per year per furnace. Virtually all units installed recently to produce ferromanganese have been electric furnaces. They are much more flexible (i.e., able to handle wider variations in ore composition and size and to produce various products besides ferromanganese) than comparable new blast furnace installations; their capital costs are appreciably lower; and they do not require blast-furnace quality coke. They do, however, depend completely on electrical energy for their heat requirements.

Domestic production of ferromanganese has declined from 1 million short tons (s.t.) in 1965 to 273,000 s.t. in 1978. This decline is largely the result of greatly increased imports, coupled with a dropoff in blast furnace production of standard ferromanganese. Since 1970, ferromanganese was produced in blast furnaces only in the captive operations of Bethlehem Steel Corporation and United States Steel Corporation; however, these operations ceased in mid-1977.

5.4 STEEL TECHNOLOGY

About 90% of all forms of manganese consumed in the United States is used in the manufacture of iron and steel. For each short ton of raw steel produced in the United States, an average of about 15 pounds of manganese is consumed (about 7.5 kg per m.t.), exclusive of manganese ores fed to the blast furnace or in scrap steel added to steelmaking furnaces. Japanese steelmakers consume less manganese per ton of steel, and USSR steelmakers consume substantially more.

5.4.1 Function of Manganese

Manganese is used for deoxidation, desulfurization, and control of morphology of sulfides and carbides in iron and steel products. Its effects on strength, toughness, hardness, and hardenability are also important.

The universal use of manganese in steelmaking results from the low cost of manganese relative to the cost of other materials or combinations of materials, and to modified steelmaking processes that might accomplish the same ends as manganese in current steelmaking practice. From a practical standpoint, there is no substitute for manganese in steelmaking. Steelmaking without the use of manganese, although possible, would adversely affect steelmaking costs. The impact would probably be so severe that manufacture and use of steel would be substantially curtailed. Alternative materials would be more expensive and their use in high-tonnage amounts for steelmaking would seriously disrupt the normal supply of the alternative materials. The metallurgical chemistry of steelmaking and the properties of steel are so dependent upon the availability of manganese that major technical-economic upheavals would result from a cutoff or substantial constraint in the supply of manganese.

5.4.2 Forms and Procedures

Manganese is used in several forms in steelmaking. These include several grades of ferromanganese, manganese and manganiferous ores, silicomanganese, electrolytic manganese metal, and occasionally, spiegeleisen. The form, and to some extent the amount of manganese used, depends on the function to be performed and its cost. Inexpensive manganese-bearing iron ores are charged as blast furnace burden to make pig iron. The manganese is reduced along with the iron and becomes an alloy in the pig iron.

Manganese used in steelmaking (as differentiated from ironmaking) is added early in the steelmaking process, late in the process, or at both stages. The function of manganese added early in the steelmaking process is to control sulfur. Relatively little of the manganese added early in the steelmaking process remains in the steel.

Ferromanganese (of various grades), silicomanganese, and, in special cases, manganese metal are usually added late in the steelmaking process for final refining. Often these additions are made in the ladle following the steelmaking furnace, and are made for final fixing of sulfur, for deoxidation, and for bringing final manganese content up to specification. Where silicomanganese can be used, manganese loss because of oxidation is suppressed by the presence of silicon, and the consumption of manganese is decreased moderately.

Procedures for the use of manganese in steelmaking are dictated by the fact that manganese is an easily oxidized element. Because steelmaking is fundamentally an oxidizing process, precautions are taken to minimize the loss of manganese by unnecessary oxidation. Most of the manganese that is lost from the steelmaking system goes to the steelmaking slag; much of the slag is then discarded.

In addition to the use of "virgin" manganese (made from ore) in steelmaking, some manganese contained in basic steelmaking slags that otherwise would go to waste is returned to blast furnaces, where some of the manganese is recovered in the pig iron. The amount of slag that can be recycled to recover basicity and manganese values is limited by the amount of undesirable elements (such as phosphorus and chromium) in the slags. Most manganese contained in steel scrap is oxidized and lost to slag when the scrap is recycled.

In steelmaking, economics is the dominant factor that determines what type, grade, and amount of manganese will be used. Economics includes costs of materials, transportation, materials handling, efficiency of utilization, and trade-offs among these. High-carbon ferromanganese is the most commonly used ferro-alloy of manganese because its cost of production is relatively low per pound of contained manganese. Low-carbon grades of ferromanganese are higher in cost than high-carbon grades because the low-carbon grades are made from high-carbon grades. However, the technology of steelmaking and the specifications of some steels (primarily low-carbon steels) sometimes dictate use of low-carbon ferromanganese.

If ferromanganese of low manganese content, all other factors being equal, would be less expensive than material containing a higher percentage of manganese, and added logistic and handling costs were to allow a net savings, the lower-manganese material would be used. Thus, the use of lower-manganese (and less expensive) ores for the manufacture of ferromanganese could be a way to extend the reserves of manganese. However, the savings in raw materials costs would have to be sufficient to overshadow increased manufacturing costs in the ferroalloy plant, higher transportation costs necessarily attending the use of lower-grade material, and probably increased costs during steelmaking. As long as high-grade reserves are available, the present technology and economics usually give little or no economic incentive for use of lower-grade material.

5.4.3 Technological Changes

Although changes in steelmaking technology may tend to lower the specific demand for manganese per ton of steel, currently identifiable technological changes are expected to have virtually no effect on the amount of terrestrial manganese deposits classified as reserves. Several trends involving changes in steelmaking technology and practices could, in time, decrease the amount of manganese consumed per ton of steel produced. These are evolutionary changes, not breakthroughs. A short description of some of these is given below.

External desulfurization of blast-furnace hot metal (pig iron) using calcium carbide or magnesium is a growing practice. This method of lowering the sulfur content of iron that is to be subsequently processed into steel means that less manganese is needed for desulfurization and for fixing the remaining sulfur in innocuous form in the finished steel.

Electric-furnace steelmaking is increasing at a modest rate as a percentage of total steelmaking. Because the loss of manganese to slag by oxidation in the electric-furnace process is 30 to 50% below the loss in basic oxygen furnace (BOF) or open-hearth steelmaking, a higher percentage of electric-furnace steelmaking will decrease demand for manganese.

Argon-oxygen decarburization (AOD) has become well established during the last decade for the production of stainless steel. AOD allows better retention of easily oxidized materials such as manganese. To the degree that AOD would be extended to the manufacture of a wider range of alloy and carbon steels, efficiency of utilization of manganese would be increased and consumption of manganese could be decreased.

Direct reduced iron (DRI) is growing rapidly worldwide as a substitute for or complement to steel scrap in electric-furnace steelmaking, but short-term growth of this practice in the United States will be low or modest, mainly for economic reasons. Because of the low sulfur content of most DRI, its use in steelmaking furnaces can lower needs for manganese. If DRI is charged to blast furnaces, a practice that will continue for economic reasons to be rare in the United States, it does pick up sulfur from the coke, so that subsequent need for manganese is unaffected.

Continuous casting of raw steel (as differentiated from the casting of ingots) increases the yield of steel products and lowers the amount of home scrap that must be recycled to the steelmaking process. By minimizing remelting and attendant loss of some manganese, continuous casting increases the overall efficiency of utilization of manganese in the steelmaking system. Currently, about 17% of U.S. steel is continuously cast. The continuous casting trend for the next decade or two will continue to be upwards at a modest rate, contributing slightly to progressively lower need for new manganese in the overall system.

Packaging of manganese alloys has been considered as a means of decreasing substantial losses during shipping and handling. Manganese alloys are frangible, so that abrasion and breakage of alloys during handling in the usual bulk form generate dusts and fines that are not utilized effectively during steelmaking. Avoidance of such losses would decrease demand for manganese. With present economics, packaging is not practical but becomes more viable as alloys become relatively more expensive.

Specifications for manganese materials for steelmaking may be broader and higher in manganese content than necessary to meet property requirements for some grades of steel. It should be possible to conserve some manganese by tightening specifications and by controlling additions of manganese more closely by using heat-by-heat analyses for residual sulfur. In general, steelmakers are aware of such "trimming" options. Observation suggests that demand for manganese in steelmaking may be somewhat sensitive to price; an increase in the price of manganese generally seems to be accompanied by a slight decrease in consumption.

Full attainment of conservation potential in the long run might lower the specific (per ton) consumption of manganese in steelmaking in the United States by up to 20 to 30%. In the short run, say several years, the conservation potential is probably in the range of 10 to 15%. Despite this potential for conservation, manganese will continue to be an essential ingredient in steelmaking, even at several times its current relative cost.

5.4.4 Other Significant Considerations

A higher value-added posture is being taken by developing nations to an increasing degree. This is resulting in an increased supply of semimanufactures (such as ferroalloys) and finished steel from countries that previously had been suppliers of raw materials and purchasers of steel products. The effects of this change on manganese supply and consumption are difficult to assess. On one hand, in a developing country, the presence of abundant supplies of manganese and low costs for labor and transportation might lower the value of the materials, thus encouraging less effective utilization and increasing the drain on reserves. On the other hand, national interests in the developing country might become more adept at matching processing conditions to the nature and extent of their reserves, and take actions that will have the effect of increasing the reserves. In the short term, neither of these possibilities is expected to have a substantial effect on the amount of manganese deposits that presently are classified as reserves.

CHAPTER 6

INDUSTRIAL IMPLICATIONS

The preceding chapters indicate clearly that the noncommunist world currently depends heavily on a limited number of manganese-producing countries, and this dependence is likely to continue or to increase over the next two decades. Since 1955 the market share of the five largest noncommunist producers has increased from 71 to 87%. Australia and Gabon have replaced Ghana and Morocco in the top five (Table 6-1). In this chapter, the industrial implications of these and other trends and possibilities in the manganese market will be discussed.

6.1 POSSIBLE SHORTAGES

In general, as the number of important producers of a commodity declines, the more susceptible that market becomes to supply problems. The larger the average market share of important producers, the greater the overall market impact of a supply problem for any one. An assessment of the likelihood, duration, and extent of potential manganese supply problems is beyond the scope of this study. The effects of a manganese shortage, should one occur, would be substantial. Conservation and substitution possibilities are quite limited, particularly in the short run, and domestic production is unlikely to become economically feasible except in the most dire emergencies. Some relief might be gained by encouraging expanded production from the smaller producing nations or by providing for the development of new capacity but this would entail a substantial time delay and probably provide only a limited manganese supply. This, however, would be the most effective alternative to, at best, a tenuous situation.

6.2 MOVEMENT OF FERROMANGANESE CAPACITY

Manganese can enter the United States as ferromanganese for direct consumption by the steel industry, or as ore for production of ferromanganese and other manganese products. Manganese imported as ore is somewhat more secure than manganese imported in ferroalloys because it requires the operation of a viable domestic ferromanganese furnacing

TABLE 6-1. PRODUCTION OF MANGANESE ORE BY SELECTED COUNTRIES
(THOUSAND SHORT TONS)

	1955	1960	1965	1970	1975	1976	1977	1978(p)
Australia	53.0	67.9	112.4	827.6	1,714.0	2,374.6	1,531.1	1.422.0
Brazil(a)	234.2	1,101.4	1.538.9	2,071.0	2,376.5	1,869.7	1,670.7	1,800.0(e)
Gabon	0.0	0.0	1,411.4	1,602.1	2,474.9	2,443.6	2,039.9	1,831.2
Ghana	604.3	600.3	665.8	446.8	450.6	343.8	321.4	347.9
India(b)	1,773.6	1,321.4	1,815.3	1,819.9	1,688.0	2,022.6	2,055.9	1,727.3
Morocco	454.3	532.5	414.3	123.9	144.3	129.3	125.2	139.1
South Africa	649.5	1,316.1	1,727.8	2,953.6	6,359.3	6,009.8	5,564.4	4,758.7

p = preliminary value
e = estimate

(a) Figures are the sum of (1) sales of direct shipping manganese ore and
(2) production of beneficiated ore.

(b) In recent years much of India's production grades were below 35% Mn. In 1976, 65% of total exports of 787,533 short tons were below 35% Mn. It is presumed that the totals include ferruginous manganese ore.

SOURCE: U.S. Bureau of Mines, Minerals Yearbooks, 1959-1977, U.S. Government Printing Office, Washington, D.C. 1976-1978 data from USBM personal communications to the Panel.

capacity and capability. But, the United States depends upon only a few nations for the bulk of its manganese, and these same nations are increasing their ferromanganese production capacity with the result that the United States is importing manganese alloys to the detriment and decline of the domestic ferromanganese manufacturing industry. Thus, should supplies of manganese ore, and particularly ferromanganese from these producers be interrupted, manganese ore would have to be imported from other worldwide sources. Because of inadequate ferromanganese production capacity. The United States would be hard pressed to utilize the raw materials. The growing dependence of the United States on imports is shown in Table 6-2 and Figure 6-1. This could be a cause for concern by the United States, but whether it should be will not be considered here.

TABLE 6-2. U.S. CONSUMPTION, PRODUCTION AND IMPORTS OF FERROMANGANESE (THOUSAND SHORT TONS, GROSS WEIGHT)

Year	Consumption	Production	Imports
1969	1,071.0	852.0	307.9
1970	1,000.6	835.5	290.9
1971	899.0	759.9	242.8
1972	968.0	800.7	348.5
1973	1,116.6	683.1	390.6
1974	1,115.4	544.4	421.2
1975	881.5	575.8	397.2
1976	898.8	482.7	537.4
1977	886.3	334.1	534.4
1978	985.6	272.5	680.4

SOURCES: U.S. Bureau of Mines, *Mineral Industries Survey*, September 1979; *Minerals Yearbook*, 1973, 1977.

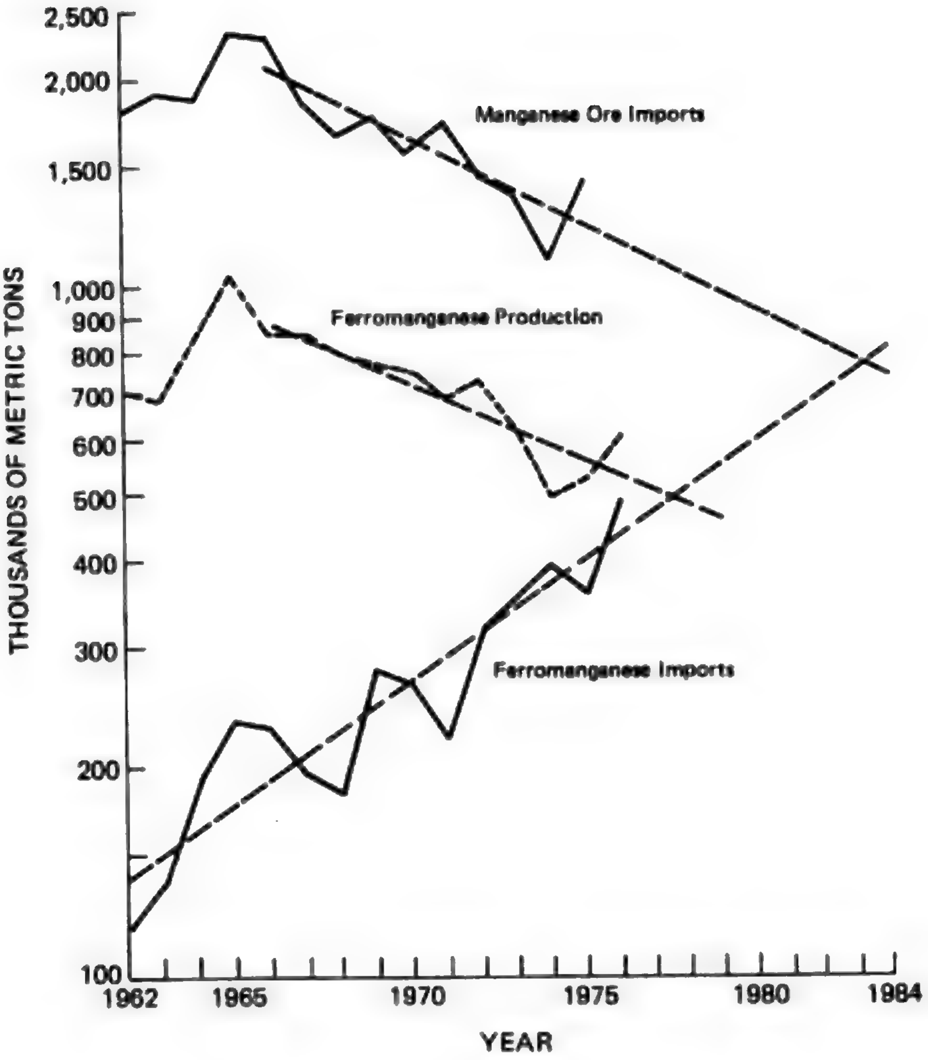

FIGURE 6-1. Trend in Ferromanganese Imports, Ferromanganese Production, and Manganese Ore Imports for United States
(Source: Table 6-2)

There are many reasons for the increase in ferromanganese imports over the 1970's. Some countries in which manganese is mined have made concerted efforts to increase the value-added in their exports; they have developed or expanded ferromanganese production capacity. Ocean shipping costs also favor ferromanganese production in countries where the ore is mined. Rising labor, capital, energy, and pollution control costs in the United States may have encouraged increased imports of ferromanganese. Lower costs for one or more of these factors, such as electric power, might help to stem or reverse the trend toward greater reliance on imports of ferromanganese.

6.3 MANGANESE SHIPPING

Both manganese ore and ferromanganese are bulk commodities. About three-fourths of the international transport of them is done by sea, in dry bulk carriers typically of 20,000 or more dead-weight tons. This has two major implications for the manganese market. First, substantial savings in shipping costs can be realized by upgrading manganese ore into ferromanganese in the country where it is mined. Using 78% and 45% as typical manganese contents of ferromanganese and ore, it can be seen that transportation costs for manganese can be reduced by 40% or more by shipping the alloy form. Second, manganese shipping can be disrupted by wars. This has not been a major factor in the manganese market since World War II and might not be important in the future, but it should be noted.

6.4 EAST-WEST TRADE

Trade in manganese between communist and noncommunist countries was negligible from the mid-1950's through the late 1970's. Manganese requirements in the communist world were met primarily by the Soviet Union and a few other, less important communist countries. The Soviet Union sometimes exported small amounts of manganese to the West. Beginning in the late 1970's, however, exports from Western countries to the communist world began to increase. If this trend continues, and communist bloc countries come to depend more and more heavily on imports from the West, added pressure will be placed on reserves and resources in the noncommunist world. For the past 25 years, the communist and noncommunist manganese markets could be viewed in isolation from each other, but in the future they must be viewed together.

6.5 MOVEMENT TO LOWER GRADE ORES

For metal mining operations in general, the most accessible, highest-grade deposits tend to be those that are developed first. As technology advances or prices increase, more remote, lower-grade, and more complex deposits can be brought into production. This is why reserves are not static; changes in prices and technology alter the amount of a metal that can be extracted economically from a deposit.

This is true of manganese as well as other metals. Some large, high-grade deposits, notably Moanda in Gabon and Groote Eylandt in Australia, have been discovered and brought into production over the past 25 years; otherwise trends generally have been toward lower grade ores. In the future, the high-grade deposits will be worked out and three possible developments will come about. The first possibility is that prices will rise to cover the production costs for deposits that are paramarginal or submarginal resources today, elevating them to reserves. The second is that mining and concentrating technology could be improved so that lower grade resources could be exploited at existing market prices. This does not seem likely unless there is a major breakthrough in technology. The third possibility is that ocean mining will become an important factor in the world manganese market. As today's high-grade deposits are worked out, they will be supplemented or replaced by deep-sea nodules as sources of manganese but this will involve the resolution of some serious political and legal issues. An intermediate course of events may be most likely; increasing prices will both encourage manganese recovery from ocean mining and elevate some resources to reserves.

As a result, resource estimates are as important to the future as reserve estimates are to the present. If there is continued exploration activity around the world, there may be discoveries of new deposits. Although possibly none will rank with Moanda or Groote Eylandt, to a great extent today's resources are tomorrow's reserves. The key issues are how long will current reserves last, and what price increase would be required to justify reclassifying paramarginal and some submarginal resources as reserves.

REFERENCES

DeHuff, G.L., Manganese, In Minerals Yearbook, U.S. Bureau of Mines, Washington, D.C., U.S. Government Printing Office, 1965, 1971, 1975.

U.S. Bureau of Mines, In Minerals Yearbook, Washington, D.C., U.S. Government Printing Office, 1973, 1975.

U.S. Bureau of Mines. Mineral Industries Survey, Washington, D.C., U.S. Bureau of Mines, September 1979.

CHAPTER SEVEN

CONCLUSIONS AND OPTIONS

7.1 CONCLUSIONS

There will be a substantial increase in worldwide demand for manganese over the next two decades, rising from about 8.7 million m.t. (manganese content) in 1977 to 19.4 million m.t. by the year 2000. U.S. manganese requirements are expected to increase from about 1.4 million m.t. to 1.9 million m.t. in the same period. Unless unforeseen major technical breakthroughs occur that will enable economic development of low-grade domestic resources or new high-grade deposits are found, the United States will continue to depend almost totally upon imports for its manganese needs.

Mineable, economic manganese reserves worldwide, as identified by the panel following the classification system reported in Table 3-4, are 4,126 million m.t. of manganese ore, or 893 million m.t. of recoverable manganese. By far the largest land reserves are in the Republic of South Africa, which indisputably has 886.6 million m.t. of ore having 248.2 million m.t. of contained manganese. The USSR has an estimated 2,279 million m.t. of ore containing 332 million m.t. of manganese, but the grade averages 20.2% manganese (weighted average of oxide/carbonate)--a lower grade than the ores considered economic in the free world. Manganese resources, exclusive of reserves, worldwide, are estimated at 34,792 million m.t. of material ranging in manganese content from about 4% to 54% and containing an estimated 2,411 million m.t. of manganese. Some of these resources will move to the reserve category as economic conditions and usage patterns change, but some will remain in the resource category.

If geographical distribution is disregarded, "in situ" reserves of manganese are adequate to meet world needs beyond the year 2000, even at projected increased consumption levels. However, there is no assurance that the physical facilities for mining, processing and transporting the manganese ore and products will be available to achieve the high level of production required, or that the political climate will be favorable toward such development or to the desired distribution of the production worldwide.

The principal free world sources of manganese currently are the Republic of South Africa, Gabon, India, Australia and Brazil. The Republic of South Africa is the major supplier of free world manganese, producing, in 1978, 4.2 million m.t. of ore having 1.7 million m.t. of contained manganese. Gabon was second, producing in 1978 about 1.7 million m.t. of ore containing 0.9 million m.t. of contained manganese. Gabon is expected to nearly double its output capacity when the Transgabonese Railway is completed. The level of production by these major suppliers is expected to continue at current or increased levels for the remainder of this century, unless unforeseen supply disruptions occur from social or political upheavals. Australia and Brazil are also expected to continue production at current or slightly increased levels. In addition, Mexico, which has large hypothetical resources, could become a significant supplier in the future. India's role as a major supplier, however, appears to be on the wane.

In the centrally planned economy countries, the USSR is a major manganese producer and probably will continue to be self-sufficient in meeting its needs for the next 30 years by using resources that are marginal or submarginal by free-world standards. Bulgaria has large hypothetical resources of manganese but it is unlikely that these will be developed in this century. Although manganese ore exports by the USSR to other centrally planned economy countries currently are about 13% of production, the exports have been declining and centrally planned economy countries' purchases of free-world, high-grade manganese ore have increased in the last decade. They can be expected to continue to increase during the rest of this century. This development might result in competition for available world supplies and cause shortages if accessibility and production does not keep pace with demand.

The bulk of the manganese consumed in the United States (almost 90%) is used in the production of iron or steel, either in the form of ore or manganese ferroalloys. Although present foundry and steelmaking practice in the United States prefers the use of standard (78% Mn) "high-carbon" ferromanganese, lower-grade ferromanganese (70-73% Mn) can be used.

Generally, in production of ferromanganese a minimum blend of 37% Mn is required for ores fed to the furnace. Because of variations in physical structure and chemical composition, blending of high-grade ores with lower-grade, less costly ores is practiced to achieve optimum furnace operation and economics. However, the availability of high-grade ores is declining and the outlook for the future is that more of the lower-grade materials will be used to produce ferromanganese. Although the technology is available for making ferromanganese from lower-grade materials, use of the lower-grade ores will increase its production costs, whether produced domestically or abroad. Because of the limited number of manganese ore suppliers, the United States and other consumers worldwide probably will have no alternative but to accept the situation. The impact of this will be that some ores now classified as resources will move into the reserve category. Also, there is a decided trend by the countries processing major reserves of ore to produce ferromanganese locally for sale in world markets. In all probability, the manganese importing nations will maintain residual production capacity but additional new ferromanganese production facilities will be located close to the sources of ore.

The quantity of manganese used for purposes other than iron and steelmaking amounts to about 10% of total U.S. demand. The oxide is used as a depolarizer in dry-cell batteries, and as an oxidant in production of a variety of chemicals. The metal also is used to prepare alloys with aluminum, magnesium, or copper. As in the case of the iron and steel industry the metal or its compounds for these other minor uses are critical raw materials.

The deep-seabed nodules of the North Pacific Ocean are a potential manganese resource. Occurrences of the nodules are extensive and the contained manganese in nodules from one area alone is estimated to be about 2.5 billion m.t. Since the mid-1960's there has been considerable activity by several consortia of companies to develop systems for mining and processing the nodules. U.S. legislation recently passed to facilitate ocean mining by companies incorporated in the United States should stimulate renewed interest in the Pacific Ocean nodules, but commercial ocean mining as an alternative to U.S. import dependence appears to be at least 10 years away. These resources are not included with the land-based resources estimates developed by the panel.

Manganese ore mining, beneficiation and processing technology used throughout the world is relatively simple and straightforward. Open-pit mining is and will continue to be the preferred method of extraction because of its lower cost and higher recoveries. However, underground mining is expanding as the high-grade, open-pit ores are being depleted. This will result in substantially higher production costs and poorer recoveries than is the case with open-pit mining. With this trend it seems likely that more attention will be given to application of new or improved methods for increasing ore extraction and extending the life of the reserve. Reducing mining costs also will receive close attention as the more difficult-to-extract ores are encountered.

As the high-grade deposits are depleted and lower-grade ores are mined, greater reliance is being placed on beneficiation to recover marketable-grade manganese products. Although the beneficiation methods used are usually simple, they are large volume operations and wasteful. In general they include crushing, screening, and heavy medium separation. The fines and rejects produced have been stockpiled at a number of operations for years. These fines contain substantial quantities of manganese. It is likely that as ore grades decline some of the fines will be retreated to recover marketable-grade manganese products, or the fines themselves will be shipped thereby extending the reserves of selected ore bodies.

Sintering and pelletizing are other beneficiation steps used to upgrade and simultaneously agglomerate manganese carbonate ores. Typical carbonate ores analyzing 20% to 30% Mn are crushed, selectively screened, pelletized, and sintered to recover an MnO product of about 40% Mn grade. Manganese recoveries are about 60% to 70% of the plant feed. As in the case of other beneficiation processes, substantial amounts of manganese are lost in the rejects that are stockpiled for future retreatment.

Based on the information and data available to the Bureau of Mines, and considering the limitations on personnel and funds, the Bureau's world manganese reserve and resources estimates are as reasonable as can be expected. Short of conducting on-the-spot, detailed geological field investigations or having access to confidential information, now unavailable from some world producers or governments, the Bureau will have to continue to assess and report reserve and resources estimates on the basis of information and data provided.

An increase in ferromanganese production capacity abroad has been detrimental to the critical and strategic aspect of the U.S. ferromanganese industry. Most new electric furnace capacity has been installed in the countries having large ore reserves or where investment conditions have been more favorable than in the United States. In many cases, favorable government attitude and assistance have been largely responsible for these investment decisions. This attitude is in contrast to the passive or free-trade philosophy of the United States. But there are also strong economic motives, such as energy and transportation costs, as well as the desire of some developing countries to capture a greater share of the value added through further processing. Because there is reasonable assurance of supply of imported manganese, U.S. steel industry output is unaffected by the decline of the domestic ferromanganese industry, so efforts to encourage investment or prevent disinvestment in ferromanganese facilities would do little to enhance our overall domestic supply situation at the present time.

With the decline in ore grade and increased demand for manganese, underground mining, beneficiation and processing of the lower-grade materials will assume increased importance. However, research in recent years to develop new or improved approaches to more efficiently and effectively carry out these operations has been largely nonproductive, and the outlook for major breakthroughs is discouraging.

Although there are adequate in situ reserves and resources of land-based manganese ore to supply world steel demands through the year 2000 and beyond, and technology to convert the ore for steel use exists, the vast majority of these ore reserves and resources are concentrated in fewer countries than the world's oil reserves. Economics favor source-country conversion of the ore to ferromanganese and there is a clear and accelerating trend to do so at the expense of the growth of the consumer nations' conversion capacities. Further concentration of conversion capacity in the few major ore-source countries is clearly to the economic, political and social advantage of those countries. The concentration of both ore and ferromanganese production capacity in these few countries and the accompanying reduction in U.S. furnace capacity will further restrict the U.S. steel industry's options to diversify the manganese resource base. Without adequate U.S. ferromanganese processing capacity, a diversified or secure ore supply, even in the U.S. stockpile, becomes a specious objective. A secure source of ferromanganese with a secure ore source could substitute for domestic capability.

Assuring U.S. access to future manganese supplies will require a long-term plan involving complex international political and economic strategies that can neither be devised nor carried out by the U.S. steel and ferromanganese industries alone. Since similar situations are being encountered in procuring other critical materials, the development and implementation of a national minerals policy is needed that recognizes and resolves the U.S. mineral dependence problems on a systems basis, rather than from a simplistic raw material approach; the complex nature of the manganese supply, processing and use chain must be considered, including such issues as world supply and demand patterns, adequacy and stability of U.S. supply sources, transportation problems, displacement of domestic ferromanganese furnacing capacity, national stockpile reserves, and diversification and development of new sources of supply.

An analysis of the world-wide manganese resources suggests that in the future the market economy nations will come to depend more heavily on a select few countries for their manganese needs than they do today. The principal suppliers are the Republic of South Africa, Gabon, Australia, and possibly Mexico. While the possibility of a cartel among these producers is remote, U.S. dependence on so few producers for such an essential metal increases the likelihood that an interruption of supplies from any one of them would have serious consequences for the U.S. economy.

7.2 OPTIONS

The policy options open to the United States to ameliorate the potential for and the consequences of interruption of supplies are limited. One option is to support an expanded Federal Stockpiling program that would provide manganese to U.S. industry in time of critical need. Currently, the stockpile has an inventory of nearly 2 million standard tons of metal equivalent. Whether or not this is adequate to meet national needs in times of supply disruptions should be a matter of concern in drafting any National Materials Policy.

Another option is diversification of supply. Ocean mining is an approach that might attain this objective. Recent U.S. legislation (P.L. 96-283) establishes an interim procedure for encouraging commercial activity in this field. Another approach is a stepped-up program of exploration worldwide to identify major new deposits--an effort that has produced results with other minerals. The self-sufficiency prospects of the United States in manganese are low (see Section B.3). However, this should not preclude additonal efforts by the U. S. Geological Survey and the U. S. Bureau of Mines to reassess what is known of U.S. resources. The panel did not undertake an in-depth examination of this because it is beyond the scope of the current study. Another possibility--to promote production of manganese from domestic ore sources, including slags--would not be a viable alternative except in the most dire circumstances because of its low cost-effectiveness (NMAB, 1976).

A third option is lowering of demand. Reductions in manganese usage in steel-making might be achieved by technological changes such as external desulfurization of hot metal, but such benefits would only be incremental.

In any case, the National Stockpile has (or should have) material that can meet national needs for a limited period.

REFERENCES

National Materials Advisory Board, Manganese Recovery Technology, Report No. NMAB-323, National Academy of Sciences, Washington, D.C., 1976.

Public Law 96-283 (H.R. 2759), Deep Seabed Hard Mineral Resources Act, 30 USC 1401 note, June 8, 1980.

GLOSSARY*

Anticlinorium -- A series of anticlines and synclines, so grouped that taken together they have the general outline of an arch; opposite of synclinorium.

Calcarenite -- Limestone or dolomite composed of coral sand, shell sand, or calcic sand derived from the erosion of limestones.

Cataclasis -- Rock deformation accomplished by fracture and rotation of mineral grains or aggregates.

Clarke Value -- The average percent of an element in the crust of the earth.

Competent --

a. Strata or rock structure combining sufficient firmness and flexibility to transmit pressure and, by flexure under thrust, to lift a superincumbent load.

b. Rock formations in which no artificial support is needed to maintain a cavefree borehole.

c. Rock capable of withstanding an applied load under given conditions without failing or collapsing.

Concretions -- An accumulation of mineral matter that forms around a center or axis of deposition after a sedimentary deposit has been laid down. Cementation consolidates the deposit as a whole, but the concretion is a body within the host rock that represents a local concentration of cementing material. The enclosing rock is less firmly cemented than the concretion. Commonly spheroidal or disk-shaped, and composed of such cementing agents as calcite, dolomite, iron oxide, or silica.

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*Most of these terms are from Dictionary of Mining, Mineral and Related Terms, compiled and edited by P. W. Thrush and the staff of the Bureau of Mines, U.S. Department of the Interior, Bureau of Mines, 1968, U.S. Government Printing Office, Washington, D.C., others from various other sources.

Continuous Miner -- Mining machine that cuts or rips ore from the face and loads it onto conveyors or into shuttle cars in a continuous operation.

Cut and Fill -- Implies a definite and characteristic sequence of mining operations: (1) breaking a slice of ore from the back; (2) removing the broken ore; and (3) introducing filling.

Epigenetic -- A term that is usually applied to mineral deposits of later origin than the enclosing rocks, or to the formation of secondary minerals by alteration; contrasted with syngenetic.

Eugeosyncline -- An orthogeosyncline, a long narrow syncline, in which volcanic rocks are abundant.

Gondite -- A spessartite (garnet)-quartz rock, probably produced by the metamorphism of manganiferous sediments.

Hornfels -- A fine-grained, nonschistose metamorphic rock resulting from contact metamorphism. Large crystals may be present and may represent either porphyroblasts or relic phenocrysts.

Hydrothermal -- Applied to magmatic emanations high in water content; the processes in which these solutions are concerned; and the rocks or ore deposits, alteration products and springs produced by them.

Hydrothermal Deposit -- A mineral deposit that originated from hot, ascending solutions.

Hypogene -- a. Group name for plutonic and metamorphic classes of rocks.

b. Applied to mineral deposits or ore deposits formed by ascending hot solutions. Contrasted with supergene.

Lacustrine -- a. Produced by or belonging to lakes.

b. Deposits which have been accumulated in freshwater lakes or marshes.

Laterite -- Red residual soil developed in humid, tropical, and subtropical regions of good drainage. It is leached of silica and contains concentrations particularly of iron oxides and hydroxides and aluminum hydroxides. It may be an ore of iron, aluminum, manganese, or nickel.

Load-Haul-Dump -- Underground mining system employing types of equipment that load the material, haul it a specified distance and dump it into a chute or bin.

Longwall -- A system of mining on straight faces 80 yards or more in length.

Metallogenetic (minerogenetic) --

a. A localized area in which mineralization has been active at one or more periods. If the mineralization has been chiefly metalliferous, the term metallogenetic is applicable.

b. Certain regions characterized by relatively abundant mineralization dominantly of one type.

Mylonitization -- The sum of the processes by which mylonites areformed. (Mylonite -- a hard, compact rock with a streaky or banded structure produced by extreme granulation.)

Nodule -- A rounded mineral accretion built of successive layers of easily handled size. Most nodules seem to be secondary, such as chert nodules, but some investigators claim others have a primary origin, such as the manganese nodules on present deep-sea floor.

Oolite -- A spherical to ellipsoidal body, 0.25 to 2 mm in diameter, which may or may not have a nucleus, and has a concentric or radial structure, or both. It is usually calcareous, but may be siliceous, hematitic, or of other composition.

Orogenic -- Pertaining to the processes by which great chains and ranges of mountains are formed.

Pisolite -- A spherical or subspherical, accretionary body over 2 mm in diameter.

Protore -- Any primary material too low in tenor to constitute ore, but from which ore may be formed through enrichment. A protore is one that cannot be produced at a profit under existing conditions, but that may become profitable with technological advances or price increases.

Replacement Deposit -- An orebody which has replaced the original country rock by means of deposition from circulating carrier fluids. A mass of ore formed by the dissolution of previous minerals and their replacement by others.

Residual -- Characteristic of, pertaining to, or consisting of residuum. Remaining essentially in place after all but the least soluble constituents have been removed; said of the material eventually resulting from the decomposition of rocks.

Residual Deposits -- By the removal of soluble material from the original substance the insoluble material remaining may form valuable residual deposits. Iron carbonates and silicates in the original rock form may be converted into practically insoluble oxides, which form iron ores as rock weathers; silica may be leached from kaolin, leaving the insoluble hydrous aluminum oxide, bauxite. Such deposits are generally formed in warm, moist climates.

Room and Pillar -- In coal and metal mining, supporting the roof by pillars left at regular intervals.

Sedimentary -- A descriptive term for rock formed of sediment, especially (1) clastic rocks, as conglomerate, sandstone, and shales, formed of fragments of other rock transported from their sources and deposited in water; or (2) rocks formed by precipitation from solution, as rock salt and gypsum, or from secretions of organisms, as most limestone.

Shelf Area -- The submerged border of a continent as of an island extending from the shoreline to the depth at which the sea floor begins to descend steeply toward the bottom of the ocean basin.

Spiegeleisen -- An additive used in steelmaking to recarburize and dioxidize the molten metal; usually has 15-30% manganese and 4.5-6.5% carbon.

Strike -- The course or bearing of the outcrop of an inclined bed or strucutre on a level surface.

Supergene -- Applied to ores or ore minerals that have been formed by generally descending waters. Ores or minerals formed by downward enrichment.

Supergene Enrichment -- Solution of metal by surface waters from the upper part of an ore deposit and its redeposition below, causing enrichment of the underlying ore.

Synclinorium -- a. A compound syncline; a closely folded belt, the broad general structure of which is synclinal. Also called synclinore.

b. A major syncline composed of many smaller folds.

Syngenetic -- A term now generally applied to mineral or ore deposits formed contemporaneously with the enclosing rocks, as contrasted with epigenetic deposits, which are of later origin than the enclosing rocks.

Talus -- A heap of coarse rock waste at the foot of a cliff, or a sheet of waste covering a slope below a cliff.

Volcanogenic Exhalation -- Any gas or vapor formed beneath the surface of the earth and escaping either through a conduit or fissure.

Volcano-sedimentary -- Rocks formed by the accumulation of sediment in water (aqueous deposits) or from air (eolian deposits) with the rock fragments consisting of volcanic debris, either detrital or pyroclastic.

Vein Deposit -- A rock fissure filled by mineral matter. Usually the formation is steep to vertical. Vein is typically long, steep and relatively narrow.

PART II

Section A (Major)

DESCRIPTION OF WORLD OCCURRENCES

SECTION A

MAJOR SOURCES

Data for each operating mine or area known to possess manganese deposits of any consequence are contained in this part of the report. Pertinent information on how the specific classification was made by the panel is presented herein. This classification follows the guidelines described in Section 3.5 The sequence of presentation is geographical (continent) and alphabetical (by country). The listing bears no relation to the importance or the size of the deposits. Section A contains the major reserves, resources and working mines. Section B describes the minor reserves, resources and potentially productive areas of overall, lesser worldwide importance. The symbols on the maps describe the type of ore deposit involved in the approximate location: ● is a major mine, ▲ is a minor mine, and * is a potential mine.

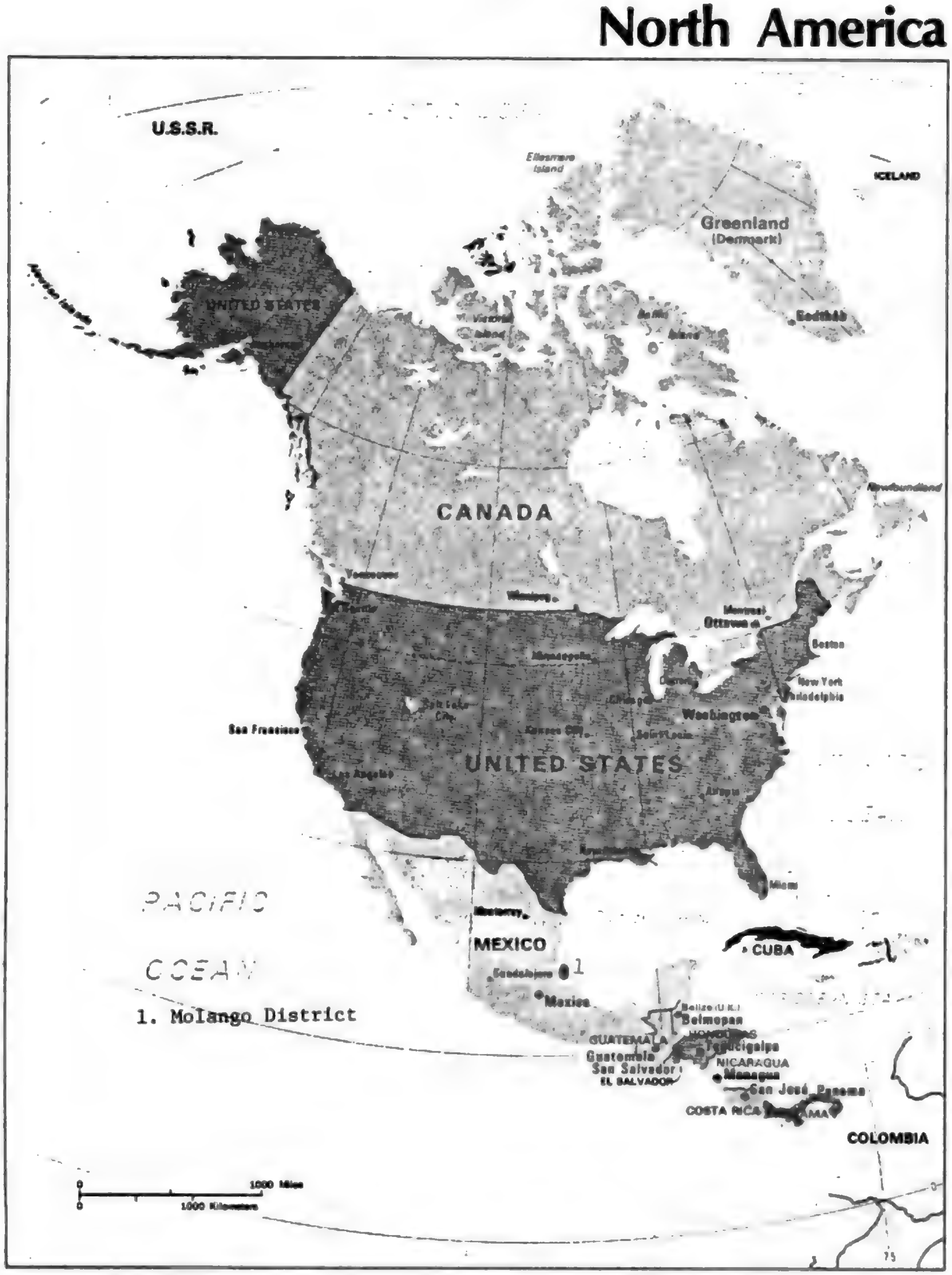


FIGURE A-1. Mexican Operating Mines (Molango District)

NORTH AMERICA

A.1 MEXICO

Most production of manganese in Mexico comes from the Molango deposits that were discovered in 1960 and put into production in 1968 by Compania Minera Autlan. Prior to the discovery of the Molango deposits, the Autlan deposit in Jalisco, depleted in the 1960's, was the leading producer. Scattered production from very small mines in Mexico continues, but is minor in comparison to the Molango deposits.

A.1.1 Molango Manganese Deposits

The manganese deposits of the Molango area are in the southeastern corner of the state of Hidalgo, Mexico, and occur within an area roughly 50 km north-south by 25 km east-west. The center of the area lies approximately 160 km north of Mexico City and 170 km southwest of Tampico. The name of the deposits derives from the small town of Molango where the original exploration office was located. The present mine and plant are in the north-central part of the area at Tetzintla and Ayotetla, respectively. The Molango area lies in the southern part of the Sierra Madre Oriental and is characterized by rugged topography, very steep slopes, and sharp mountain peaks. Relief in the area is about 1,600 m with a maximum elevation of 1,700 m above sea level.

The manganese deposits occur in, or are associated with, an extensive unit of manganiferous limestone in the Upper Jurassic Taman Formation. The manganiferous limestone is from 30 to 50 m thick, averaging about 35 m, and has a manganese content that ranges from 5% to 30% manganese, with the higher values near the base of the unit. The base of the manganiferous limestone is between 50 m and 100 m below the top of the Taman Formation. The manganiferous unit has a strike length of over 50 km along the structure of the Sierra Madre Oriental. It gradually pinches out to the extreme northwest of the Molango area and is covered on the south by other sediments and volcanic flows. The manganiferous unit, although continuous as a lithologic unit within the area, is not continuous with respect to manganese content. Much of the unit is too low-grade to be economically important in the foreseeable future.

Two types of manganese deposits are recognized in the Molango area. The most important is syngenetic in origin and was formed by chemical precipitation as carbonates during the accumulation of Upper Jurassic sediments. The second type is epigenetic. The epigenetic deposits are oxides, relatively small and scattered but locally quite rich.

The syngenetic deposits consist of the manganese-bearing carbonate minerals kutnahorite, rhodochrosite, and manganoan calcite. Gangue minerals are quartz, pyrite, clay minerals, and organic carbonaceous material. The bulk of the manganiferous unit is a fine-grained, thinly laminated calcium-manganese carbonate rock with gangue minerals disseminated throughout the groundmass in thin layers, generally along bedding planes. Some secondary quartz-calcite (and rhodochrosite) veins crosscut the bedding.

The epigenetic deposits are derived directly from the syngenetic carbonate deposits by oxidation and supergene enrichment in areas where conditions of structure, topography, and drainage were favorable. The epigenetic deposits grade from slightly leached, manganiferous limestone to massive accumulations of manganese oxides, hydrated in part. The predominant mineralogical phase is a poorly crystalline nsutite, with small amounts of pyrolusite and ramsdellite. The epigenetic deposits have proven to be excellent sources of manganese of the active type suitable for dry-cell batteries.

The Molango area is part of a large regional anticlinorium that trends northwest-southeast, parallel to the axis of the Sierra Madre Oriental. The central part of the anticlinorium is deeply eroded, exposing the Precambrian-basement complex, and successively younger rocks are exposed from the core outward. The core of the anticlinorium is flanked by smaller, asymmetrical, secondary folds. Locally, there is intense flexural deformation with associated thrust faulting. The mine at Tetzintla is on the southwest flank of an asymmetrical anticline whose axial plane dips about 60° to the southwest and whose axis plunges about 10° to the northwest. The fold at Tetzintla grades from open, slightly asymmetrical at the northwest end of the mine to tight and distinctly asymmetrical in the center of the mine to thrusted and asymmetrical at the southeast end of the mine.

A.1.1.1 Production and Chemistry

Manganese-carbonate production is from both open-pit and underground operations. The manganiferous unit is being mined by open-pit to a depth of about 175 m and by a modified, retreating, sublevel caving method beneath the open pit. In 1980, about 52% of the carbonate ore for the nodulizing plant was mined underground. By 1985, as mining progresses to new areas, relatively more open-pit carbonate ore will be available so that underground mining will drop to 42%. These figures are exclusive of the production of high-grade epigenetic ore, all of which comes from shallow pits not exceeding 30 m in depth.

Crude mine production for 1980 is estimated at 925,000 m.t., of which about 371,000 m.t. will be from open-pit and 554,000 m.t. will be from underground. Open-pit production and about 30% of underground production are fed directly to the beneficiation plant. The remaining 70% of underground production is passed through a heavy media process that recovers about 60% of the material as concentrate for plant feed. A total of about 83% of crude ore ends up as plant feed.

The carbonate ore is fed to a nodulizing plant that consists of a crushing and blending operation and a rotary kiln. The kiln dries, calcines, and nodulizes the carbonate ore to a final MnO_2 product containing about 40% manganese and representing about 60% of the weight of the plant feed. A typical analysis of the carbonate ore is:

Mn	Fe	SiO_2	Al_2O_3	CaO	MgO	S	CO_2
27.0%	7.1%	13.3%	2.5%	4.4%	4.4%	1.8%	28.0%

Estimated plant feed for the next 10 years is shown in Table A-1:

TABLE A-1. ESTIMATED PLANT FEED, 1980-1989 (1000 m.t.)

	1980	1981	1982	1983	1984	1985-1989
Open Pit	370	420	840	1,150	1,080	995
Underground	400	430	360	200	420	705
Total	770	850	1,200	1,350	1,500	1,700

Production of oxide ore is about 40,000 m.t. per year, averaging 73% MnO_2. Crude ore is treated in a washing plant that recovers crushed material to one-fourth inch (6.35 mm). Finer material is stored for future retreatment. Recovery in the plant is currently about 70%. A typical analysis of crude oxide ore is:

Mn	Fe	SiO_2	Al_2O_3	CaO	MgO	C	P_2O_5	S	IL
50%	5.8%	2.9%	2.0%	0.4%	1.0%	0.1%	0.1%	0.005%	10.2%

Non-ore carbonate material grading 15% to 20% manganese, which is mainly from stripping in the open-pit, is stockpiled. Resource carbonate material grading 10% to 15% manganese is left in place.

Within the blocked-out reserves, carbonate ore is quite persistent. The cut-off grade is 20% manganese and is a function of distance from the base of the unit; the grade decreases gradually upward from the base of the manganiferous limestone.

A.1.1.2 Reserves

Cia. Minera Autlan (personal communication) provided the following reserve figures for carbonate ore: Proven--30 million m.t. at +27% manganese; Probable--1.5 billion m.t. at +25% manganese.

Based on reconnaissance, geological mapping, and sampling, of the manganiferous limestone unit throughout the Molango District, Autlan estimates recoverable resources of 14 billion m.t. at about 10% manganese. Reserves of proved oxide ore are presently estimated at 1.5 million m.t. Figures in Table A-2, provided by Autlan, appear to fit the Bulletin 1450-A Classification System:

TABLE A-2. MOLANGO DISTRICT MANGANESE DEPOSIT (1000 m.t.)

	Measured	Indicated	Inferred	Hypothetical Resource
Manganese Carbonate	10,000	20,000	200,000	15,300,000
Manganese Oxide	500	1,000		
Totals	10,500	21,000	200,000	15,300,000

Diamond drilling is continuously in progress to extend the identified reserves. The object of drilling is to attempt to maintain a 20:1 ratio of reserves to annual production. The intensity of development of the reserves is determined by the projected production schedule.

A.1.2 Other Deposits in Mexico

There are a few other producing mines in Mexico, but all are small. All of the product, so far as known, is consumed domestically. Table A-3 shows total metric tons of manganese as the element produced in 1977:

TABLE A-3

State	District	Manganese (as the element) (Metric Tons)
Chihuahua	Buena Ventura	2,382
	Allende	43
	Zaragoza	177
Durango	Lerdo	1,277
	Mapimi	694
	Tepehuanes	384
Hidalgo	Pachuca	5,150
Michoacan	Coalcoman	179
San Luis Potosi	Charcas	4,163
Zacatecas	Villa de Cos	1,634

The ore in most of these is probably oxide of good quality, and mining would be by hand or by very simple mechanical methods.

In addition to these operating properties, there are a very large number of deposits and occurrences with small reserves scattered around the country that, when added to the reserves of the operating properties, may total a few hundred thousand tons of oxide ore. This could be considered an inferred reserve, but because of their small size, production from any one of these deposits will not have any significant impact on the manganese market compared to Molango.

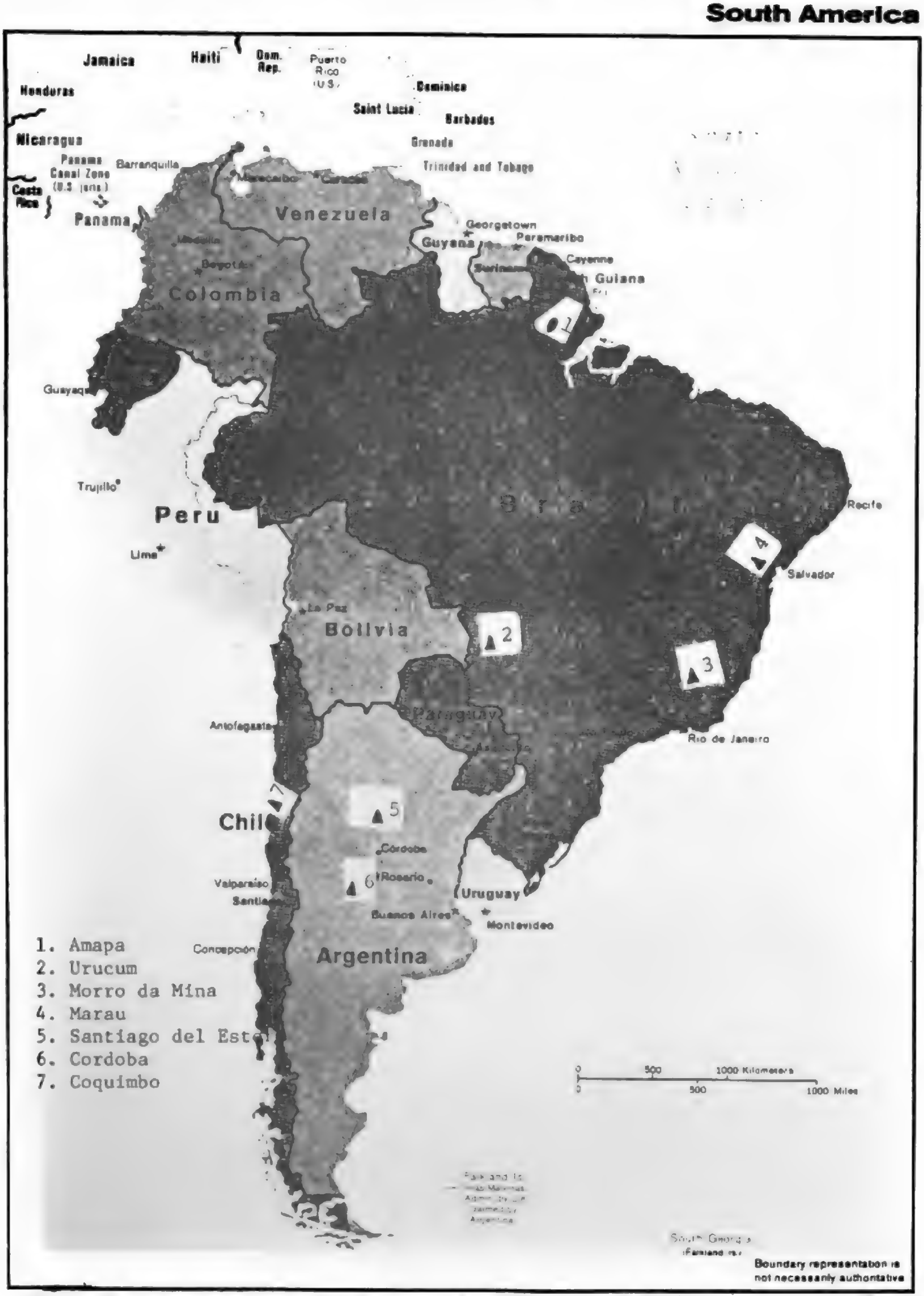


FIGURE A-2. Operating Mines in Argentina, Brazil and Chile

SOUTH AMERICA

A.2 BOLIVIA

A.2.1 Mutun Manganese Deposit

The Mutun deposits of iron and manganese ores in Bolivia are an extension of deposits mined on the Brazilian side of Serra do Mutun. In 1975, exploration was in progress on these deposits by the Empresa Minera Mutun, S.A. (SIDERSA) a Bolivian company. No later information is available.

Access to the SIDERSA camp was by road about 55 km from Corumba, Mato Grosso, Brazil. The manganese bed, which had been opened by an adit by SIDERSA, was 18 km by road from the SIDERSA camp, and only 5 km north of the Jacadigo manganese mine in Mato Grosso, Brazil. The adit, 43 m long, had been driven into the manganese bed. Manganese oxides have been found in talus in the direction of Jacadigo, but these occurrences had not been prospected.

The manganese-oxide bed exposed in the adit ranges from 1.2 to 1.6 m thick and assayed 52% manganese and 8% iron. The ore consists of hard, highly fractured cryptomelane that is unevenly layered. Layers of soft, brownish, limonitic-appearing mineral, 3 mm to 20 mm thick, occur within the manganese bed. These layers are subparallel to the attitude of the manganese bed which dips from 10° to 30° to the southwest.

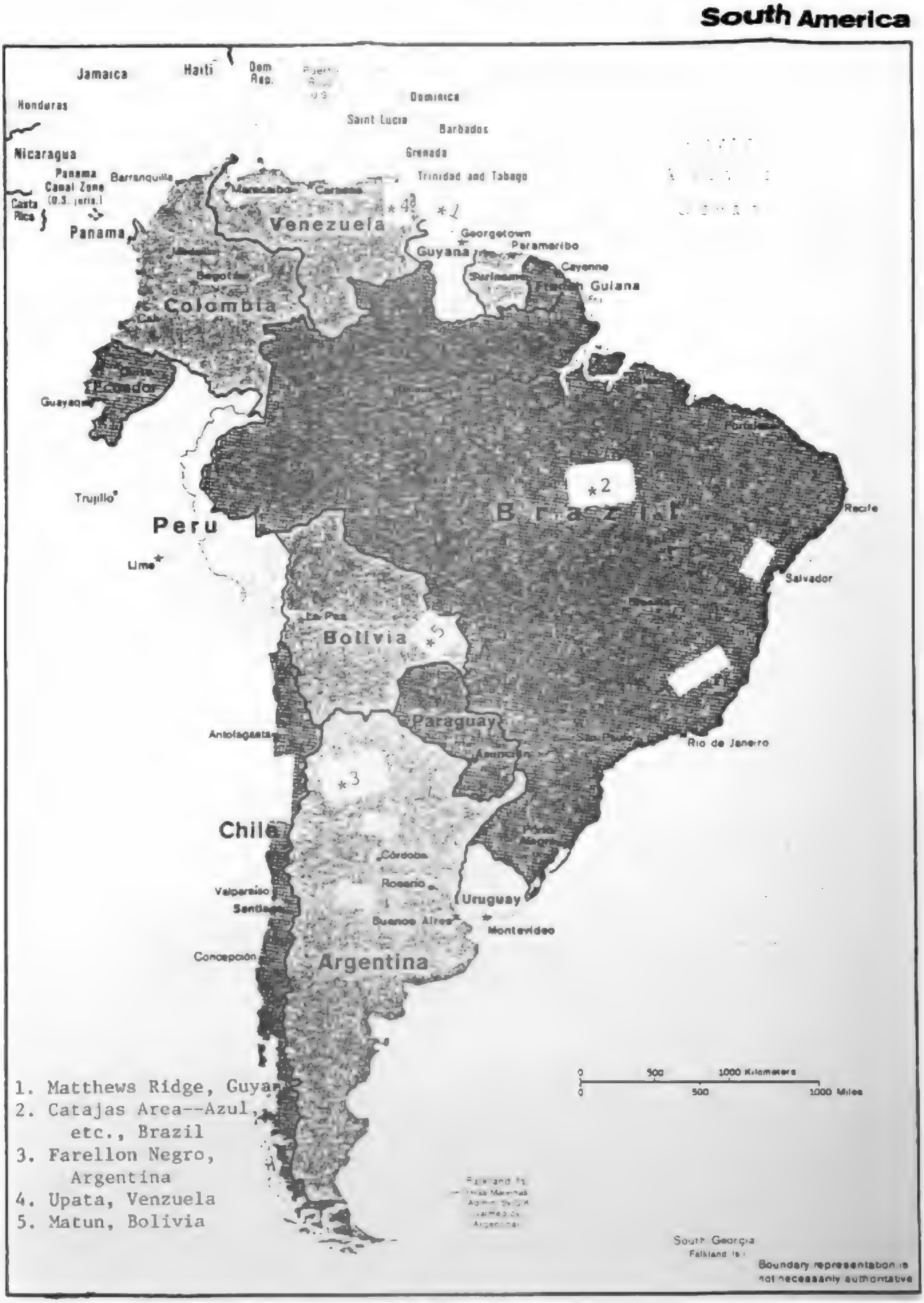
Thick siliceous iron formation, with magnetite-bearing lenses as much as 20 cm thick, lies above the manganese bed and extends to 20 m below it. The iron formation is said to contain 55% iron; silica is the only visible impurity.

No manganese or iron ores have been shipped from the Mutun area in Bolivia. The river town of Puerto Buschi, 104 km south of the deposits on the Paraguay River, had been selected as the shipping port for any eventual ore production.

SIDERSA did not provide any estimates of manganese reserves. If the deposits are co-extensive with the iron formation, a subeconomic resource on the order of 60 million m.t. could be estimated over an area of 15 square km. Lacking supportive or detailed work, Bolivia is not listed in the Resource Tables 3-7 or 3-8.

A.3 BRAZIL

Brazil is the fifth ranking producer of manganese ore among the free market countries after the Republic of South Africa, Gabon, Australia, and India. Manganese deposits are distributed throughout Brazil and at least some production has been recorded from most Brazilian states and territories. The deposits of Minas Gerais were the first to be exploited for exportation.



1. Matthews Ridge, Guya
2. Catajas Area--Azul, etc., Brazil
3. Farellon Negro, Argentina
4. Upata, Venzuela
5. Matun, Bolivia

South America Potential Mines

The Serra do Navio mine in the Territory of Amapa has been the largest producer and exporter of manganese ore since 1957. Smaller, discontinuous exports have been made from the large deposits of the Corumba district of Mato Grosso. Large tonnages of manganese in the recently discovered Azul and Buritirama deposits in the Carajas iron district of Para may eventually be available for export.

Production for domestic use comes from manganese carbonate protores at Morro da Mina in Minas Gerais, oxide ores from the Marau mine in Bahia, and from numerous small but fairly high-grade deposits in Goias. A recently installed ferromanganese furnace at Corumba, Mato Grosso, uses Urucum ore from the Corumba district.

Brazil imports manganese from South Africa and in the future may permit exports only to the extent that production is greater than domestic requirements and it is economically advantageous to satisfy part of the domestic requirements with imported manganese.

A.3.1 Geology

All of the manganese deposits of Brazil originated as Precambrian manganiferous oxide sediments associated with iron formation, or as Precambrian manganiferous carbonate-silicate sediments. Many of the smaller deposits in Minas Gerais and the large deposits in the Corumba district are associated with iron formation. Manganese-carbonate protores were the source for the large oxide ore bodies of Serra do Navio and Morro da Mina.

Most of the high-grade manganese-oxide ore bodies were developed from lower-grade manganiferous sediments by a process of selective replacement by manganese, accompanied by leaching of impurities from the protores under tropical weathering conditions. These deposits can be classed as residual lateritic concentrations. In general, the iron, alumina, silica, and alkali contents are lowest in those ore bodies that have been most intensely weathered. In the Corumba district in western Mato Grosso, the relatively high-grade ore at Urucum appears to be related to the high manganese oxide content of the original sediment, with only minor reworking and concentration through weathering processes.

A.3.2 Serra do Navio Mine, Federal Territory of Amapa

The Serra do Navio mine lies 196 km by rail north of the shipping port of Santana on the North Channel of the Amazon River. Although located in the midst of the Amazon rain forest, these large, high-grade deposits prompted planning for a major investment in transportation, plant, and port facilities soon after their discovery.

Industria e Comercio de Minerios, S.A. (ICOMI), a Brazilian company formed by Companhia Auxiliar de Empresas de Mineracao S.A. (CAIMI) (51%) and Bethlehem Steel Corporation (49%) explored and developed the deposits, beginning in 1949. Production began in 1957 and has continued to the present.

A.3.2.1 Production

Production through 1979 was 20.75 million m.t. of washed ore grading 48.5% Mn, 5.8% Fe, 2.5% SiO_2 and 5.2% Al_2O_3. A reduction roast-pelletizing plant utilizing nonmarketable fines was put into operation in 1975. The plant, with an annual capacity of 200,000 m.t. of pellets, produced 700,000 tons through 1979. The pellets grade 55.1% Mn, 6.3% Fe, 5.2% SiO_2, 6.5% Al_2O_3, 0.09% P, and 1.05% K_2O plus Na_2O. Current annual capacity (1980) is 800,000 m.t. of plus 5/16 in. washed ore and 200,000 m.t. of pellets.

A.3.2.2 Mining

Serra do Navio is an open-pit mine. Four shovels remove the ore in five-meter-high benches and load into dump trucks. Depending upon the hardness of the ore, the benches are dynamited or scarified. As mining has progressed to lower levels below the ridge crests, the ore has become softer so that some of it can be loaded by the shovels directly from the face. Waste rock, consisting of clay formed from weathered schist, is stripped with tractors and pans. Depending on grade of crude, two to three million m.t. of ore and six million m.t. of waste are loaded annually.

A.3.2.3 Beneficiation

A washing plant, heavy media plant, and Humphrey spirals, are located at the mine. The pellet plant circuit at Santana includes a magnetic separator. At the mine, crude ore is crushed, washed, and screened. The coarse products, plus 5/16 in. lump ore, minus 5/16 in. and plus 1/4 in. "bitomiudo," are conveyed to bins at the railhead. The "bitomiudo" may be ground to finer size for pellet feed. Two fine ore products, locally called "miudo" and "fines," are of lower grade, running less than 43% manganese. Initially they were stockpiled because there was no ready market. The miudo product is now concentrated in a Dynawhirl, heavy-media, ferrosilicon circuit and the fines pass through a Humphrey spiral circuit. Both circuits reduce the alumina and silica content of the ore and bring the grade up to about 45% manganese and 7% iron. The combined plant capacity is 290,000 m.t. annually.

At the pelletizing plant the concentrate is reduction roasted, wet ground in a ball mill, and routed over four single-drum, permanent magnet separators. The magnetic fraction is wasted and the nonmagnetic fraction is filtered, dried, formed into 6 mm to 19 mm balls, and heat-hardened on a straight grade machine at a maximum temperature of 1,260°C. The combination of reduction roasting, magnetic iron removal, and addition of "bitomiudo" fines raises the pellet grade to 55.1% manganese.

A.3.2.4 Reserves

The principal ore minerals are cryptomelane and pyrolusite. Minor manganese minerals include hausmannite, lithiophorite, and manganite. The oxide ore formed thick cappings up to 150 m wide along ridge crests, replacing the protore layer downward as much as 130 m to the lowest level of the weathered zone. At the lowest level of weathering, the oxide ore exhibits a sharp contact with the carbonate-silicate protore.

Four ore types are recognized at Serra do Navio:

(1) Hard ore is the hard, massive, highest-grade ore that occurs nearest the surface and has contributed most of the lump ore.

(2) Schistose ore is high-grade manganese oxide that replaces the weathered schist along foliation and fracture planes. The clay content is high, but it is readily removed in the washing plant.

(3) Gonditic ore contains relicts of the silicate minerals in the protore and is of lower grade than the hard ore.

(4) Lateritic ore is float ore. It consists of boulders of hard ore and concentrically layered "granzon" or pellets of manganese oxides, found in the lateritic red clays on the slopes of the ridges below the hard ore croppings.

Reserves at Serra do Navio may be classified as "Identified" with most ore (80%) in the "Measured" category. Identified reserves as of January 1, 1980, are 16,124,000 m.t. of crude ore that will yield 5,788,000 m.t. of plus 5/16 in. marketable washed lump ore grading 48.3% manganese. The miudo and fines washing plant product (minus 1/4 in.) is estimated at 3,198,000 m.t. and the intermediate washing plant product (bitomiudo 1/4 in. to 5/16 in.) at 723,000 m.t. Together, these will yield 2,317,000 m.t. of marketable pellets.

At a production rate of 800,000 m.t. of lump ore per year, the mine has a life of seven years. Pellet plant production at the rate of 200,000 m.t. per year would permit an additional three to four years of operation from stockpiles.

A subeconomic resource of 5 million m.t. of manganese carbonate-silicate has been estimated. Thorough testing of a bulk sample failed to produce a commercially acceptable product; hence this tonnage has not been listed in Resource Tables 3-7 and 3-8. A further complication is that the ore will have to be mined underground.

Extensive prospecting in the mine area and throughout the general region has failed to locate any new deposits. However, some additional tonnage has been located each year as drilling continues around the fringes and at depth in the known deposits. Mine life could be extended a year or more beyond the estimated seven years if this program succeeds in the next few years as it has in the past.

A.3.3 Corumba District, Mato Grosso

South of the city of Corumba, Mato Grosso, there is a mountainous complex composed of arkosic sediments topped by a thick iron formation. One or more beds of primary manganese-oxide sediments occur at or near the base of the iron formation. Three mines, the Urucum, the Santana, and the Jacadigo, were in production in 1979.

The deposits of the Corumba district have not been thoroughly explored. Where mined, the lowest bed of manganese ore ranges from two to four meters thick. The beds are gently dipping, and their location beneath the steep escarpment formed by the overlying iron formation requires underground mining. Although outcrops of the manganese beds are largely obscured by talus, it is possible that the manganese beds are as extensive laterally as the iron formation. If so, the reserves could total more than 100 million tons. However, the ore is of marginally commercial grade because of its low manganese to iron ratio and high potash content. The long river haulage and low-tonnage rail capacity to shipping ports restrict production capability. There has been little incentive to invest in an extensive drilling program to establish the reserves with any degree of confidence.

A.3.3.1 Urucum Mine

The Urucum mine in the Morro do Urucum is 30 km by road from the river port of Ladario near Corumba. The earliest production of manganese was in 1912. A Brazilian company, Sobramil, shipped about 43,000 m.t. from 1941 to 1943 (Dorr, 1945). Sobramil eventually entered into an agreement with Companhia Meridional de Mineracao to mine and export the ore and from 1957 to December 1972 some 900,000 m.t. were barged down the Paraguay River to the ocean shipping port of Nuevo Palmire in Uruguay. (Personal communication with Sr. Francisco Fara, General Manager at Corumba for Meridional, January 1973.) In 1975 the state of Mato Grosso joined with Companhia Vale do Rio Doce (CVRD) to form a new company, Urucum Mineracao, to explore and mine the concessions. Production resumed in 1977 and reached an estimated 150,000 m.t. in 1978.

There are two beds of manganese at Morro do Urucum. Mining has been in the lowest bed which ranges between three and four meters in thickness. The upper bed, separated from the lower bed by about 35 m of iron formation, averages 1.2 m in thickness. Typical ore averages 46% Mn, 13% Fe, less than 3% SiO_2, 1.7% Al_2O_3, and nearly 4% K_2O.

The ore is mined by a room and pillar system. The broken ore is slushed down to simple loading chutes for rail haulage to the mine mouth. There it is crushed to six inches over a grizzly and hauled by truck to Ladario for river shipment. Except for crushing and screening out the minus 1/4 in. (6.35 mm) material, the ore is not beneficiated. At Urucum, in contrast to other deposits in the Corumba district, the ore is massive and contains no weathered arkose, quartz, and clay impurities.

In 1979, Urucum Mineracao cited reserves for the lower manganese bed in the North Block at 16 million tons and the South Block at 28 million m.t. (Preston, 1979). This reserve is based on a bed thickness of 2.7 to 2.8 m in the South Block, where mining has been active. Preston (1979) presents the Urucum reserves as shown in Table A-4:

TABLE A-4. URUCUM MINE RESERVES AND RESOURCES

	Reserves				Other
In situ, million m.t.	Measured	Indicated	Inferred	Total	Resources
Lower bed - South Block	2.0	13.0	13.0	28.0	0
Lower bed - North Block	0.5	1.5	14.0	16.0	0
Upper bed	0	0	0	0	60.4
Total	2.5	14.5	27.0	44.0	60.4

The estimated resource of 60.4 million m.t. for the upper bed is too high considering that it is thinner than the lower bed. A resource figure of 15 million m.t., as shown in Resource Table 3-8, would appear more reasonable. Dorr (1945) estimated the upper bed at 9.5 million m.t. of measured, indicated, and inferred ore, or 13.2 million m.t. for the total area.

A.3.3.2 Other Deposits in the Corumba District

Manganese ore is also found in Serra do Rabicho, Serra do Mutum, Tromba dos Macacos, Serra do Santa Cruz, and Serra Sao Domingo. Two small mines, the Santana and the Jacadigo, are producing small tonnages from the Serra do Rabicho and the Serra do Mutum respectively. Except for the Santana mine, none of these localities has been explored in any detail. Any estimate of manganese resources is based upon a rough measurement of the potential manganiferous area and an assumed thickness of any bed that may be present. This resource is on the order of 130 million m.t., but more detailed exploration is required to establish a demonstrated reserve.

Santana Mine, Serra do Rabicho. The Santana mine has produced hematite float ore grading 66% iron, as well as manganese, for several years. The manganese bed, probably the lower bed as at Morro do Urucum, had been mined in four shallow inclined pits. In 1975, two new adits were opened by Mineracao Mato Grosso and in 1978, they reportedly provided 50,000 m.t. of ore to the new ferromanganese plant at Corumba operated by Companhia Paulista de Ferroligas.

The manganese bed can be traced over a distance of 650 m along the outcrop. Dipping 15° to the east, it ranges in thickness from 2.5 to 4.0 m, with most of the manganese oxides concentrated in the lower part of the bed. Cryptomelane occurs as thin, irregular layers and roughly stratified layers of nodules in a matrix of coarse sand and clay derived from weathered arkose. The overlying and underlying strata are arkosic sediments. The top arkose layer is about 3 m thick and grades upward into siliceous iron formation.

Reserves at the Santana property were estimated in 1975 as shown in Table A-5.

TABLE A-5. SANTANA MINE RESERVES ESTIMATES (THOUSANDS OF m.t.)

	Crude Ore		Washed Ore		Washed
	Indicated	Inferred	Indicated	Inferred	%Mn
Upper part of bed	691	1,001	221	320	41.4
Lower part of bed	824	1,192	379	584	48.2
Total	1,515	2,193	600	904	45.6

SOURCE: ICOMI internal report

The indicated and inferred ore reserves are limited on the west by the outcrop, on the north and south by the concession limits of Mineracao Mato Grosso, and on the east by an arbitrary down-dip limit.

Jacadigo Mine, Serra do Mutum. At the Jacadigo mine a company known as Sobraimoveis is reported to be producing some 40,000 m.t. of ore per year. The ore is mined by rudimentary methods on the outcrop. It is then hand sorted and dumped into a chute leading down to a place accessible by road for loading onto trucks and haulage to Ladario. This ore is similar to that at the Santana mine, with nodules and irregular layers of cryptomelane mixed with quartz and clay. No analyses of the ore or reserve estimates are available, and the deposit is not listed in Resource Tables 3-7 or 3-8.

A.3.4 Carajas Region, State of Para

Three manganese deposits, Azul, Buritirama, and Sereno, have been discovered in recent years in the region of the huge high-grade iron ore district of the Serra dos Carajas, Para, north central Brazil.

A.3.4.1 Azul Deposits

The Azul deposits were discovered in 1971 by Companhia Meridional de Mineracao, a subsidiary of U.S. Steel Corporation, in the course of exploring and evaluating the Carajas iron deposits. The iron and manganese deposits are now under the control of Amazonia Mineracao (AMZA), an affiliate of Companhia Vale de Rio Doce (CVRD). The Azul deposits lie between the north and south limbs of a synclinorium composed of the Precambrian Grao Para Group of metasediments, iron formation, and volcanic rocks. The manganese deposits lie above manganiferous pelitic shales of the Rio Fresco Formation that unconformably overlies the Grao Para Group (Anderson et al., 1974). The in-place ore was derived from weathering of two shaly protore beds running 14 to 36% manganese and an interveining layer running only 2 to 4% manganese. A 900 km railroad, from the coast near Sao Luis, Maranhao to the Carajas district, must be constructed to serve this relatively new iron-manganese district.

Exploration by Meridional consisted of pitting and some diamond drilling. An analysis of typical, washed 40% manganese material is 58.95% MnO_2, 9.4% Fe_2O_3, 4.10% SiO_2, 13.27% Al_2O_3, 1.25% K_2O, 0.43% BaO, trace of Li_2O, 0.05% Na, and 9.06% H_2O. The washing tests indicated a yield of 1.9 m.t. of washed ore per cubic meter in residual accumulations of surface ore derived from the enrichment of the manganiferous shales.

Resources at the Azul deposit were cited at 10 million m.t. for many years. Recent exploration has significantly increased the tonnage. Preston (1979) cites crude ore resources as estimated by Amazonia Mineracao in April 1977, as shown in Table A-6.

TABLE A-6. AZUL CRUDE ORE RESOURCES ESTIMATES (THOUSANDS OF m.t.)*

	In-Place Resources				Percent
	Measured	Indicated	Inferred	Total	Manganese
Detrital	9,800	10,400	4,000	24,300	35-50
Lump	0	15,300	0	15,300	44
Fines	0	24,600	0	24,600	28
Total	9,800	50,300	4,000	64,200	

*Figures rounded by the panel

More recent information (ICOMI, personal communication, 1979) gave a crude ore resource of 65 million m.t. which would wash to 44 million m.t. of product grading 46.5% manganese. Of this, 25% is said to be larger than 1/4 in. It is not clear from information available that the resource picture at Azul and in the surrounding region is complete. Additional prospecting may find more ore, but no attempt is made here to estimate any additional resource.

A.3.4.2 Buritirama

The Buritirama deposits are located in the basin of the Itacaiuna river about 50 km north of the Carajas iron deposits at Serra do Norte. These deposits, like the Azul deposits, were discovered and prospected by the Companhia Meridional de Mineracao.

Nine separate deposits have been found over a distance of 31 km. Most of these are small, with an average length of about 180 m. Samples from 26 localities gave a weighted average of 47.29% Mn, 3.31% Fe, and 5.31% SiO_2. One deposit designated "B5" was prospected thoroughly. Oxide ore extends for 1,400 m with a width ranging from 35 to 340 m and a thickness ranging from 5 to 30 m. The deposit was explored by 3,200 m of shallow trenches, 27 diamond drill holes, and two tunnels 100 m and 121 m long, respectively.

The surface ore is hard and dense, but grades downward into soft, pulverent oxide ore of lower manganese and higher SiO_2 and Al_2O_3 content. The origin of the Buritirama deposits appears to be similar to the Serra do Navio deposits, with weathering and enrichment of a manganese carbonate-silicate protore. Much of the ore is described as fines that could be screened to provide an acceptable concentrate (Anderson et al., 1974). Analyses of crude ore from the tunnels gave the following: 27-51% Mn, 1.9-5.1% Fe, 1.9-18% SiO_2, 6-18% Al_2O_3, 0.06-1.22% P, 0.09-0.22% Na_2O, 1.21-2.77% K_2O, and 1.3-2.0% BaO.

Total identified resources are estimated to be 11 million m.t. along the known extent of the ore. As in the case of Azul, the resources picture is probably not complete, but no attempt to estimate additional resources has been made.

A.3.4.3 Sereno

The Sereno manganese deposits lie 85 km to the east of the Serra dos Carajas and 65 km southeast of Buritirama. These deposits are genetically similar to the Buritirama deposits, but they are smaller and more widely scattered. Resources of oxide ore are estimated at 2.8 million m.t. in 28 deposits. Massive manganese oxide is found as enriched crusts on the surface, but at shallow depth the fine pulverent manganiferous rock assays only 19.4% manganese.

A.3.5 Morro da Mina, Minas Gerais

At the Morro da Mina mine at Conselheiro Lafaiete, Minas Gerais, the high-grade manganese oxide ores derived from carbonate-silicate protores are nearly exhausted. Present production comes from calcination of the protore. Between 1902 and 1956, more than 6 million m.t. of oxide ore were produced, mainly from open-pit operations.

Calcination involves the operation of 3 vertical furnaces with a daily capacity of 150 m.t. each. Every 1.35 m.t. of furnace feed produces 1.0 m.t. of product grading 38 to 40% Mn, 3 to 5% Fe, 6% Al O , 18 to 22% SiO_2, and 2 to 3% loss on ignition. Most of the product is used locally in small furnaces to manufacture ferro- and silicomanganese.

Protore reserves are not completely known. For the purpose of this report, a figure of three million m.t. of inferred ore is used.

A.3.6 Marau, Bahia

The Marau deposits near Salvador, Bahia contain an estimated six million tons of ore in a vein-like structure that extends for eight km and ranges in thickness from one to eight m. The ore assays 38 to 40% Mn, 5% Fe, 4.5% SiO_2, and 11% Al_2O_3. Ore minerals are cryptomelane, lithiophorite, and pyrolusite.

The deposits are controlled by a Brazilian ferroalloy manufacturer, FIBRASA, that operates other small mines in Brazil. The Marau deposits have been inadequately explored and are being worked by primitive methods.

A.3.7 Other Deposits in Brazil

A great many small deposits are scattered throughout the states of Bahia, Minas Gerais, Goias, and others. Some of these deposits may have been mined out, while some more probably would be termed "mineral occurrences." Many have not been mined because they are remote from consuming centers and until recent years were mostly inaccessible. A total resource of 14 million m.t., evenly split between inferred and resource, is included in Table A-7.

A.3.8 Summary

Brazil has fairly large identified manganese reserves and for several years at least should continue to be an important supplier of ore on the world market. Table A-7 tabulates the crude ore reserves and resources according to categories.

TABLE A-7. SUMMARY OF RESERVES AND RESOURCES OF CRUDE ORE IN BRAZIL (THOUSANDS OF m.t.)

	Reserves			Other
	Measured	Indicated	Inferred	Resources
Serra do Navio	12,800	3,200	-	5,000
Corumba area				
Urucum	2,500	14,500	27,000	15,000
Santana	-	1,515	2,193	-
Others	-	-	-	130,000
Carajas area				
Azul	-	-	-	64,460
Buritirama	-	-	-	11,000
Sereno	-	-	-	2,800
Morro da Mina	-	-	3,000	-
Marau	-	-	6,000	-
All Others	-	-	-	14,000
Totals	15,300	19,215	38,193	242,260

Total Reserves (rounded)	72,700
Total Other Resources (rounded)	242,300
TOTAL	315,000

Note: Dash (-) = Denotes no data assigned by the panel to this category.

Considering only ore from identified reserves, applying estimated beneficiation factors and an underground mining recovery factor at Urucum, estimated product reserves and grades are shown in Table A-8.

TABLE A-8. SUMMARY OF IDENTIFIED RESERVES PRODUCT ESTIMATES

	Reserves (1,000 m.t.)	Percent Manganese
Serra do Navio - lump ore	5,788	48
- pellets	2,317	55
Corumba - Urucum - ROM ore	26,400	46
- Santana - washed ore	1,504	46
Bahia - Marau	4,000	43
Minas Gerais - Moro da Mina	1,500	27
Total	41,509	

The question of additional resources in Brazil is difficult to answer with any degree of confidence. Certainly it is a vast country and undiscovered deposits of manganese may exist. However, the very size of Brazil, the great distances involved, the difficulty of careful and detailed work in the jungle areas, the hazards to health and equipment, the dense cover of vegetation and the deep alteration of most rocks, and other factors make prospecting slow, expensive, and arduous. It appears that the Corumba and Carajas areas offer the most promise for Brazil to maintain its overseas manganese markets. To compete, however, these ores must be upgraded and transportation facilities constructed or vastly improved. In view of the pending depletion of Serroa do Navio and the time span required for new transportation construction, Brazil may become a net importer of manganese ores and ferromanganese within ten years.

REFERENCES

Ahreu, S.F., Vol. 1, Recursos Minerais do Brasil, Minsterio da Industria e do Comercio. Instituto Nacional de Tecnologia, Rio de Janeiro, Brazil, 1962.

Anderson, W.L., Dyer, R.C., and Torres, D.D, Ocurrencias de Manganes na Bacia do Rio Itacaiunas, Centro-Leste do Estado do Para, 25th Congresso Geologico Brasileiro, Sociedade Brasileira de Geologia, 1974.

Barbosa, O., Manganese at Urucum, State of Mato Grosso, Brazil, Symposium del Manganeso, Twentieth International Geological Congress, Vol. III, America, pp. 261-274, Mexico, 1956

Dominguez, E.C., Pelletizing Manganese Ore Fines at ICOMI, Brazil, In Second International Symposium on Agglomeration, Proceedings of American Institute of Mining, Metallurgical and Petroleum Engineers, 1977.

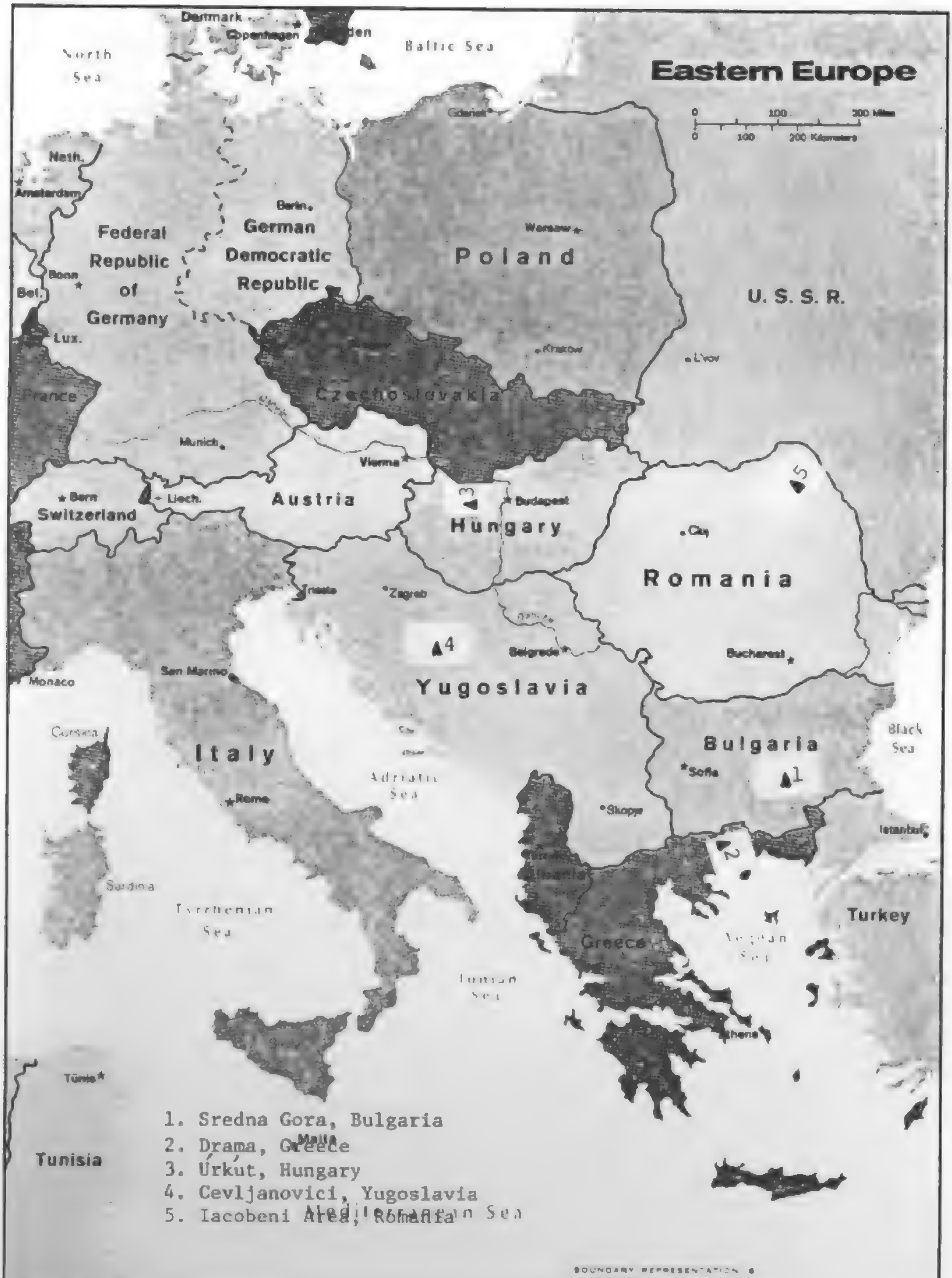
Dorr, J.V.N., II, Manganese and Iron Deposits of Morro do Urucum, Mato Grasso, Brazil, U.S. Geological Survey Bulletin 946-A., U.S. Government Printing Office, Washington, D. C., 1945.

Nagell, R.H., Geology of the Serra do Navio Manganese Deposits, Economic Geology 57/4, pp. 481-498, 1962.

Preston, W.A., Manganese Ore Reserves and Resources, British Steel Corporation, Private Report to the committee, 1979.

The TEX Report 11/2537, TEX Report, Ltd., Tokyo, Japan, July 17, 1979.

Whitehead, C.H., Visit to the Azul Manganese Deposit, Serra doe Carajas, Para, Brazil, Australia and New Zealand Exploration Company, private report, 1976.



1. Sredna Gora, Bulgaria
2. Drama, Greece
3. Úrkút, Hungary
4. Cevljanovici, Yugoslavia
5. Iacobeni Area, Romania

FIGURE A-4. Operating Mines in Southeastern Europe

EUROPE

A.4 BULGARIA

In spite of an intensive effort to increase domestic supply, typical of countries with centrally planned economies since World War II, Bulgaria is heavily dependent on the USSR for metallurgical manganese ore. The manganese balance of 1975 is estimated to be as follows: requirement for crude steel of 2,265,000 m.t.--about 45,000 m.t. manganese; local production--about 10,000 m.t. manganese in 35,000 m.t. ore containing 28.5% manganese; exported (to East Germany?)--2,300 m.t. manganese; and balance of requirement--37,300 m.t. manganese from USSR, in 126,000 m.t. of ore/concentrate--about 30% manganese.

Manganese ore production rose from almost nothing in 1948 to a peak of 81,000 m.t. in 1957 and was 40,000 m.t. in 1978. In recent years oxide ore grade has dropped from about 30 to 27.5% manganese.

A.4.1 Sredna Gora Deposits

The main source of local manganese-oxide production has been from the volcanogenic-sedimentary metallogenetic zone, running nearly east-west from Sofia, past Plovdiv to Burgas. This is the central part of the Kraishte-Burgas synclinorium, in which there are considerable masses of andesites, and Cretaceous clastics, as well as some limestone. Ferruginous manganese deposits, related to submarine lava outflows, occur at many places along the belt. Most of these are small and unimportant.

Typical modest deposits are the Pozharevo occurrences, 39 in all, 23 km northwest of Sofia. Cataclastically dislocated orebodies, with mylonitization and faulting, are in contact with andesites and overlying marl or tuff at a depth of about 50 m. The structure of these deposits, explored by underground drifts, is very complicated. They extend laterally for 160 m and are 1.5 to 4.5 m thick. Aggregate potential is only about 100,000 m.t., with ore chemistry as follows: Mn 17 to 48%; Fe 0.3 to 9.6%; SiO_2 11 to 55%; Al_2O_3 6.8% maximum; and low P, 0.02 to 0.06%. Ore minerals are pyrolusite, psilomelane, rarely manganite, and braunite intergrown with opal and chalcedony so that the material is very siliceous. "First-grade" ore has 31 to 32% manganese plus 28% SiO_2, "second-grade" similar manganese plus 32% SiO_2, while "third-grade" has 28.5% manganese plus 34.3% SiO_2.

Manganese showings with negligible potential are typified by localities on the Rilska and Struma Rivers, near the Macedonia border. Veinlets of wad, hematite, and pyrolusite occur in a 2 m central band in a 10 to 15 m crushed zone in schistose and injection gneisses and Pliocene sands. Length is several meters to tens of meters. Some superficial manganese oxidation occurs, but grade is very low. Rocks are steeply dipping and oxidation cannot persist at depth.

A.4.2 Varna Belt Resources

The largest manganese resource potential in Bulgaria is part of the great Oligocene deposits of the southern USSR. Manganese carbonate and silicates, with some superficial oxidation similar to Nikopol', occur at the base of the Oligocene over a large coastal area, extending 15 to 25 km inland from Blatnitsa in the north to Byala in the south, with Obrochishte centered between Varna and Kavarna. The resource has been developed by 17 boreholes, as well as by outcrops on both sides of the Provadiya River at the villages of Ignatiev, Pripek, Rudnik, Byala, and others. Ore is also developed by a shaft in the Obrochishte area. Cover depth in the vicinity of the southern outcrop ores ranges from 2 to 70 m. Some small amount of oxide shallow ore is developed with 29 to 39% manganese, some of which has been worked. Thickness of three beds aggregates 9 to 10 m. Potential of individual occurrences such as Byala, Rudnik, Pripek, and Ignatiev are each in the order of 10,000 to 50,000 m.t. of high silica (40% SiO_2), high phosphorus (0.2 to 0.25%) resource, with 20 to 30% manganese as oxide ore and 13 to 21% manganese as carbonate ore. Aggregate potential of economic parts of the formation was given in 1961 by Iovchev as 13,170,000 m.t., containing 2,710,000 m.t. (20.5%) manganese, and "resources" were 15,730,000 m.t. at 2,410,000 m.t. contained manganese.

A.4.3 Obrochishte Resources

In the Obrochishte area proper, as in Nikopol', the manganese occurs at the base of the Oligocene in silty and glauconitic clay, succeeded by marls and more silts. The total thickness of the Oligocene, where it outcrops, is 175 to 360 m, with the manganiferous bed, ranging from 2 to 24 m, at the bottom. At Obrochishte No. 1 shaft, the thickness is 11.30 m. Ore is pisolitic and concretionary; oxide ore is absent. Pisolite minerals are manganese hydrosilicates and manganese carbonate, with accessory pyrite and alabandite suggesting high sulphur. There is evidence of hydrothermal activity and barite occurrences in some places, so accessory metals may be suspected. Manganese carbonates are rhodochrosite and manganocalcite.

This resource is quite low-grade. Manganese ranges from 6 to 18% with silica uniformly high at 38 to 48%. Iron is generally less than 2%, Al_2O_3 at 4 to 7%, alkalies 2.5%, lime plus magnesia about 15%, and phosphorous, as in Nikopol', at 0.1 to 0.4%. It is intimately mixed with calcian rhodochrosite. The chemistry and depth suggest a submarginal resource.

The Obrochishte area proper is about 52 km^2, which would give the rather large potential of 1.5 billion m.t. of 10% manganese material with a thickness of 10 m and a density of 3. Boreholes indicate the horizon both in the north and the south of the Varna Belt, over a distance of 100 km. Based on these widely separated points of observation, the hypothetical and speculative resources (C_2) might be an additional 6 billion m.t. at 10% manganese if half the total area is underlain by the carbonate, with an average thickness of 2 m (Iovchev, 1961).

A.4.4 Manganese Resources in Iron Ores

The Kremikovtsi iron ore deposit, 25 km northeast of Sofia, consists of sideritic and hematitic ore, at 150 m depth under Pliocene alluvium. Ore is capped by up to 100 m of limonite. Iovchev (1961) gives reserves as 247 million m.t. averaging 30.3% iron and 6.2% manganese, with 15 million m.t. of recoverable contained manganese. Ore is developed on a drill grid of 50 to 100 m, with over 300 holes. About 133 million are B, 80 million C_1, and the balance A. The sedimentary-hydrothermal deposits are high in lead (0.2 to 1.2%) and $BaSO_4$ reaches 18.4%, both undesirable manganese contaminants. This is a submarginal manganese resource with poor chemistry, and as a manganiferous iron ore, does not qualify for inclusion.

The Martin iron ore, near the village of Chiprovtsi in northwest Bulgaria 75 km northwest of Sofia and near the Macedonian border, has 7.6 million m.t. of 23% iron-siderite ore with 6.5% manganese (i.e., 114 thousand m.t. contained manganese). The deposit is a sulphide complex with 1-3% Pb, 1% Zn, high S (1.5%), and As 0.3%. Because of high contaminants and small tonnage, this resource has little practical significance.

A.4.5 Manganese Reserve Summary

Table A-9 gives reserves by categories (Iovchev, 1961). Note that +20% manganese is considered ore in the "reserve balance" (balansovi zapasi), while generally all lower grades are in the "nonreserve balance" (izvanbalansovi zapasi). Recovery is not given but assumed to be high since much is open-pit.

The Iovchev figures were distributed as follows in Tables 3-7 and 3-8: A_2 + B category reserves were totalled in measured and C_1 (or B + C, where unseparated) were totalled under inferred. The grades were weight-averaged and 75% recovery of manganese was assumed. Because of the low grade and carbonate mineralogy of the Kalamantis material, it was assigned to submarginal resources, although in Table A-9 10.363 million m.t. are shown as reserves of C_2 type. Although the Iovchev figures are somewhat dated, they are believed to be representative because production since 1961 was not more than 60 million m.t. of crude ore in aggregate.

TABLE A-9. Manganese Reserves and Resources in Bulgaria

District Name of Occurence and Ore Type	Reserve Category	Reserve ("Balansovi")			Non-reserve (Resource)		
		Ore 1000 m.t.	Mean % Mn	Cont. Mn 1000 m.t.	Ore 1000 m.t.	Mean % Mn	Cont. Mn 1000 m.t.
I. Varna District							
1. Ignatiev							
a. Varna part	A_2+B	42.1	25.29	10.647			
oxide ore	C_1	-	-	-	48.0	14.40	6.912
Mixed oxide Carbonate	-	-	-	-	-	-	-
b. Pripek	A_2+B	55.6	20.70	11.509	-	-	-
oxide ore							
Mixed oxide	A_2+B	1,000.0	23.2	232.200	-	-	-
& carbonate	C_1	1,083.5	21.9	237.286	415.5	16.36	67.976
c. Kalimantsi/ Ignatiev Part carbonate ore	C_2	10,362.5	20.3	2,103.587	4,435.3	13.80	612.058
2. Rudnik							
oxide ore	C_1	4.0	27.11	1.084	-	-	-
carbonate ore	$B+C_1$	566.0	17.89	101.237	4,130.7	16.20	669.173
	C_2	-	-	-	5,051.5	15.60	788.034
3. Byala							
a. Karadepe oxide ore	C_1	7.0	28.38	1.987	-	-	-
b. Goritsa carbonate ore	B	47.8	22.63	10.817	-	-	-
c. Byala Part	C_1	-	-	-	63.4	24.40	15.470
Mixed oxide & carbonate	C_2	-	-	-	204.5	23.60	48.262
4. Byeloslav ox.&carbonate	C_1	-	-	-	1,380.0	14.80	204.340
TOTAL VARNA	$A_2+B+C_1+C_2$	13,168.5	20.54	2705.374	15728.8	15.34	2,412.125
II. K'rdzhali Dist.							
Eniovche	C_1	-	-	-	-	-	-
III. Sofia Dist.							
Pozharevo	A_2+B	3.2	29.89	0.956	-	-	-
Mine oxide	C_1	1.1	29.36	0.323	-	-	-
TOTAL SOFIA	A_2+B+C_1	4.3	29.76	1.279			
GRAND TOTAL	$A_2+B+C_1+C_2$	13,172.8	20.35	2,706.653	15,728.3	15.34	2,412.125

SOURCE: Iovchev, Y. Sm. "Mineral Resources in the Peoples' Republic of Bulgaria" Sofia, Tekhnika Press, 1961. (Polezni Izkopaemi na B'lgariya)

REFERENCES

Aleksiev, B. and Bogdanova, K., The Obrochishte Manganese Deposit, Twelve Ore Deposits of Bulgaria, International Association of Genesic (sic) of Ore Deposits 4th Symposium, Varna, Sofia Bulgaria, 1974.

Bulgaria, Mining Annual Review, Mining Journal, page 595, London, U.K., 1979.

Dimitrov, T. and Kostov, I., On the Origin of the Manganese Ore Deposits in the Srednogorian Zone. (In Bulgarian, Engl. res.: Vrkhu Genezata na Manganorudnite Mestorozhdeniya v srednogorieto) Vol. XLVII/2- Geology 1952/53 - 1953/54, Godishnik na Sofiickiya Universitet, pp. 23-61, 1952.

Iovchev, Y.S., Mineral Resources in the Peoples' Republic of Bulgaria, In Bulgarian; Polezni Izkopaemi na N.R. B'ulgariya, pp. 75-88, 106-107, 124-127, 141, Figs, 33-35, Tekhnika Press, Sofia, Bulgaria, 1961.

Janakiev, G., Metalliferous Mining in Bulgaria, Mining Magazine, 114/4 p. 267, April 1966.

Keefe, E. K., Area Handbook for Bulgaria, U. S. Government Printing Office, Washington, D.C.; 1974, pp. 48, 257-258, 1974.

Nachev, I.K. and Nasheva, L., On the Mechanism of Formation of Obrochishte Manganese Deposit, Lower Oligocene, Varna Region, Bulgaria, Acta Mineralogica Petrographica Szeged Hungary XXI/2, p. 312, 1974.

Nikolayev, G., Contemporary Manganese Mineralization in the Vicinity of Stob Village, Kyustendil District, In Bulgarian, S'vremenni manganovi orudyavaniya v okolnostite na. s. Stob, kyustendilsko, Vol. XIV/2. Godishnik na Visshiya Minno-Geolozhki Institut, pp. 236-242, Sofia, Bulgaria, 1970.

Anonymous. Large Metal Deposits Reported Discovered in Bulgaria EMJ--Metal and Mineral Markets, Vol. 217, NO. 30, p. 11, 26 July 1956,.

Sapozhnikov, D.G., Editor, Manganese Deposits of the Soviet Union, Izdatel'stvo, Nauka Moscow, (Translated from Russian, Jerusalem, 1970) 522 p, 1967.

Stefanov, H. and Dobrev, D., Structural Peculiarities of the Pozharevo Manganese Occurrences, In Bulgarian: Strukturni Osobenosti na pozharevskoto manganovo nakhodische. Godishnik na Visshiya Minno-Geolozhki Institut, XVII/II Sofia 59-69, 1970-1971.

U.S. Bureau of Mines, Minerals Yearbook, The Mineral Industry of Bulgaria, U.S. Government Printing Office, Washington, D. C.: preprint, pp. 4,6, 1976.

Varentsov, I.M., Sedimentary Manganese Ores, Elsevier Scientific Publishing Company, Amsterdam, Holland, p. 56, 1964.

Weiss, S.A., Manganese, The Other uses, In, Metal Bulletin Books, Ltd. Garden City Press, Ltd., Hertfordshire, U. K., pp. 105-106, 1977.

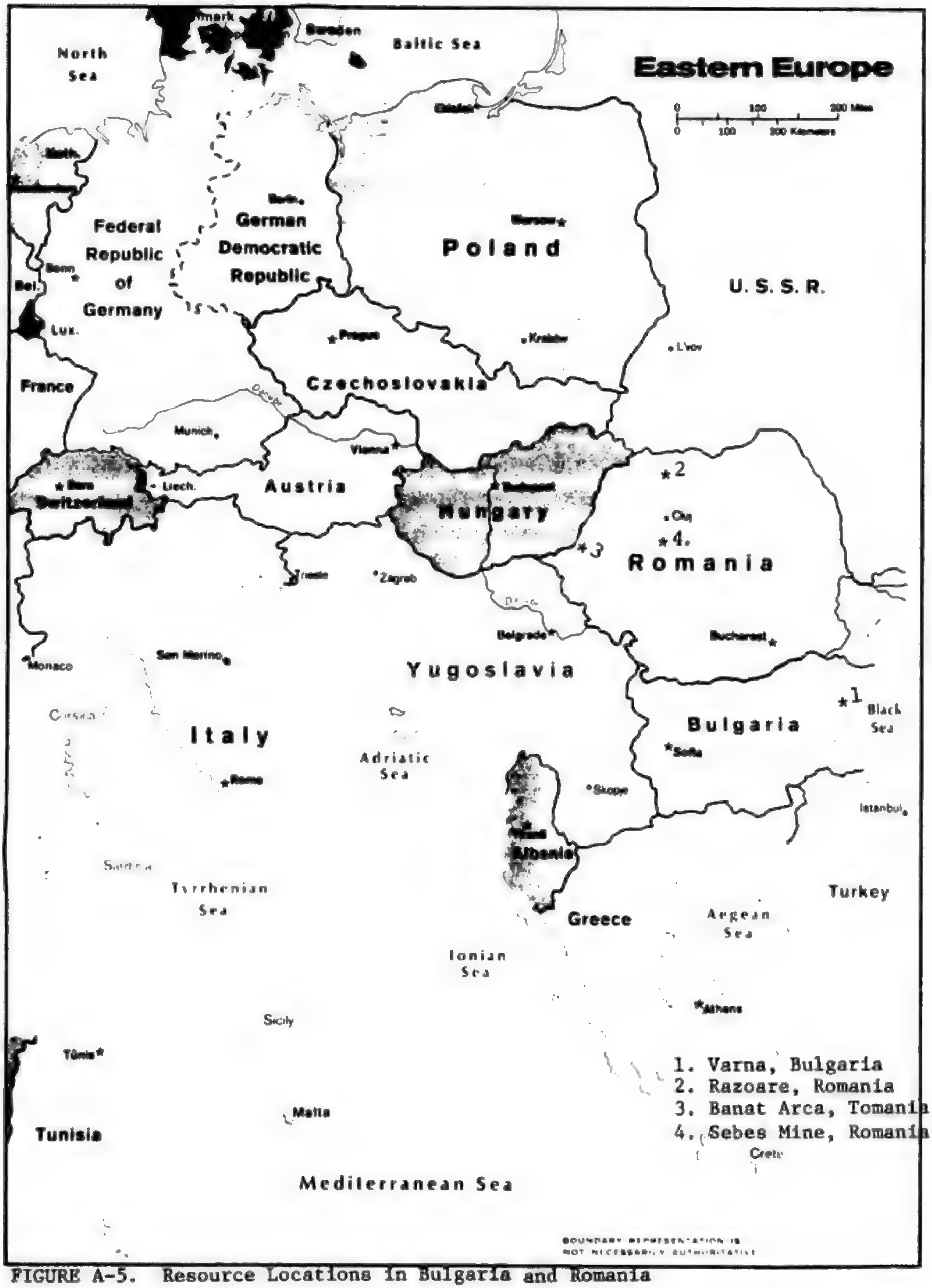


FIGURE A-5. Resource Locations in Bulgaria and Romania

A.5 HUNGARY

The two deposits of any significance are Urkut, 20 km northwest of Balatonfoered (i.e., north of the center of Lake Balaton) and Epleny, 15 km, by rail, north of Veszprem in the Bakony Mountains. In 1974 total Hungarian production was given as 127,000 m.t. of oxide ore and 54,000 of carbonate ore. At Urkut, there are 3 underground mining shafts, at depths of 100 to 200 m. At Epleny, oxide outcrop discovered in 1928 was mined by open-pit until exhausted. It is now mined by shafts at a depth of about 250 m, where a bed 6 to 8 m thick and ranging to a maximum of 20 m is nearly horizontal, but mildly contorted.

A.5.1 Ore Grades

At Urkut carbonate crude grades 20.5% Mn, 9.9% Fe, up to 0.5% P and 21.7% SiO_2. Oxide ore is manganite, psilomelane, and pyrolusite. The carbonate ore is rhodochrosite. Phosphorus occurs as a secondary apatite low in fluorine (dahllite). The most frequently recurring phosphorus value is 0.25%.

At Epleny, oxide ore has 24.4% Mn, 10.7% Fe, 0.25% P and 20.36% SiO_2, including interbeds of waste. Without interbeds, manganese assay is 30 to 36%. The carbonate ore contains 14% Mn, 4% Fe, 22.8% SiO_2, and 0.15% P.

A.5.2 Beneficiation

As neither the oxide ore nor the carbonate ore is suitable material for ferroalloys (because of the low manganese content and low manganese-to-iron ratio) or for blast furnace additions (because of the high phosphorus), beneficiation has been applied at Urkut, which has greater reserves than Epleny.

Forty tons per hour (tph) of crude ore at about 33% manganese are washed by an Excelsior washer and by hydrocyclones. Washed ore has 38.5% manganese that represents a 33% recovery. The product contains 56% Mn, 9% Fe, 7.5% SiO_2, and 0.18% P.

Calcining crude ore of 32% manganese is reported to raise the grade to 36% manganese, which, after magnetic separation, will yield a product of 51.7% manganese with 2.3% iron and high (0.12%) phosphorus. Manganese yield is 61%. The product is reported to be uneconomical. Matte smelting of manganese failed to produce a MnO slag of satisfactory composition for ferromanganese manufacture.

A.5.3 Reserves

In view of limited usability, the material should be classified as a resource. In fact, Horvath, et al. (1979) states that it is more economical to import high-grade oxide ore from less-developed countries.

Urkut is considered to be syngenetic sedimentary carbonate ore of lower- to mid-Eocene and thus could have some persistence. Remaining oxide at Urkut is irregular and of secondary enrichment. Epleny is considered to have some primary oxide, plus carbonate and secondary oxide enrichment; these wedge out over 1 km along the strike and 400 m across the strike. Exploration at Urkut probably included more than 300 holes (spacing unavailable) and the carbonate layers in aggregate may be up to 100 m thick.

Hungarian resources, presumably mainly at Urkut, are given as 25 million m.t. of oxide ore -- of which only 15,000 m.t. are minable. Additionally these may be 500 to 600 million m.t. of manganese carbonate resources.

The quantities are believed to be material in place. Total product resources available, after allowing for the usual mining losses plus those of the washer, would be in the order of 215 million m.t. of carbonate ore containing perhaps 20.5% manganese (i.e., 45 million m.t. of recoverable contained manganese, assuming a reasonable continuity of mineralization).

A.5.4 Resources

All the crude material is considered a resource rather than a reserve. Combined cyclone sands at 25% Mn and slimes at 15% Mn, with 16 to 17% Fe and 16 to 27% SiO_2, are being produced at 26 m.t. per hour (tph) when plant is running, or possibly at a rate of 100,000 m.t. annually. This represents a potential lower-grade resource of 100 million m.t. of 25% manganese (cyclone sand) and 240 million m.t. of 15% manganese (slimes). The 25% product is reported as unsuitable for economic spiegel production. Both of these material types fall more appropriately into the classification of ferruginous manganese ores and hence are excluded from the Resource Tables 3-7 and 3-8.

REFERENCES

Kedves, M. and Simoncsics, P., Investigation of Spores and Pollen Grains of the Carbonate Manganese Ore Bore Hole Samples from Urkut. Acta Mineralogica-Petrographica, Szeged XX/1, pp. 85-96, 1971.

Horvath, J., Horvath, A., and Pentek, I., Complex Utilization of Manganese Ores in Special Consideration of the Role of Manganese in Agriculture, Vasipari Kutato Intezet, Steel Research Institute, Budapest, Hungary, June 12, 1979.

Grasselly, G., Szabo, Z., Bardossy, G., and Nemeth, J.C., Data on the Mineralogy and Geology of the Manganese Ore Deposit of Epleny, Acta Mineralogica-Petrographica Szeged, XIX/1, pp. 15-43, 1969.

Grasselly, G., On The Phosphorous-Bearing Mineral of the Manganese Oxide Ore Deposits of Epleny and Urkut, Acta Mineralogica-Petrographica, Szeged XVIII/2, pp. 73-83, 1968.

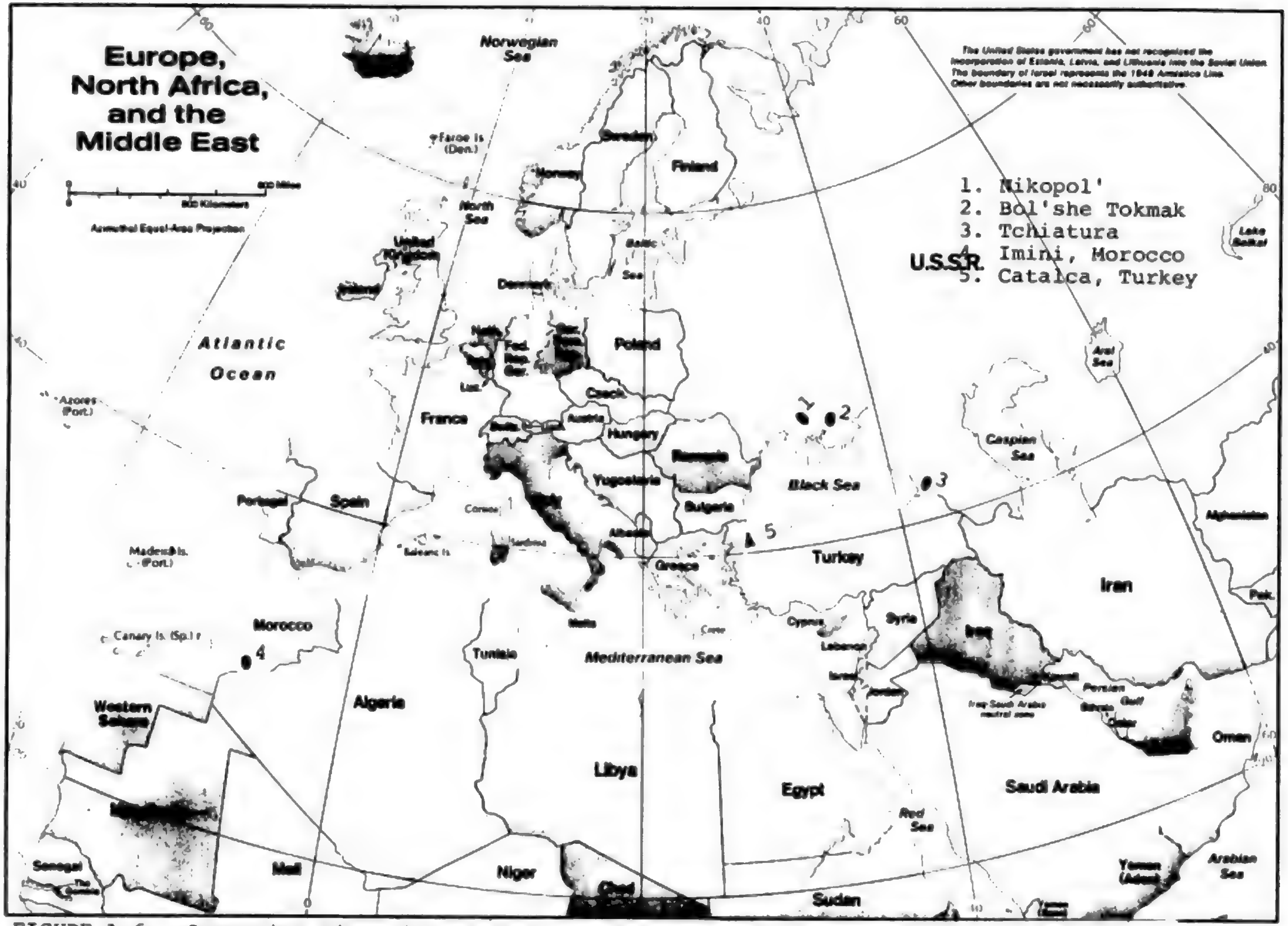


FIGURE A-6. Operating Mines in Morocco, Turkey and Southeast USSR

A.6 UNION OF SOVIET SOCIALIST REPUBLICS

A.6.1 Summary of Essential Characteristics

A.6.1.1 Southern Ukrainian Basin - Nikopol'

Some 82.4% of the economic reserves (balansovye zapasi) of the USSR are found in the Nikopol' manganese district of the southern Ukraine, shown in Figure A-7. This district accounts for about 72% of the USSR production of contained manganese units in concentrate, i.e., about 2.6 million m.t. contained manganese per year. Originally all manganese was mined underground. However, deep-stripping operations have increased from 11% in 1955 to 76.5% in 1971. This has improved extraction, but at a higher cost. Ores can be used to make standard ferromanganese after upgrading, but by western standards the product is expensive after the extensive concentrating and sintering steps and is high in phosphorous and ignition loss.

The Southern Ukrainian manganese ore basin has been well explored and no new significant discoveries that would materially add to reserves are expected. The bulk of reserve additions were made during the period of intensive investigation from 1950 to 1958. Nothing significant has been added since then, so that the reserve addition curve, as shown by Boyarskiy (1975) is slightly in decline. Sapozhnikov (1967) states that the problem of good ore reserves in European SSR in the principal manganese-producing districts (Ukraine, Georgia) is becoming acute.

The average life of the open-pit Nikopol' reserves, as derived in the reserve analysis, is calculated at 31 years as of late 1979. Boyarskiy (1975) states that the total quantity of investigated and presently active reserves of manganese ore should assure the All-Union 1980 production level for 30 years. This appears reasonably consistent.

The bulk of the operations are highly-mechanized, deep-strip mining, using tremendous complements of giant-sized earth-moving machines such as bucket-wheel excavators. The low-grade crude ore mining is followed by complex beneficiation. Consequently, the operations are carefully planned and rigidly scheduled for quinquennial plans. In such a system, where there is no high-grade ore suitable for the market economies, even though production easily could be increased by simple methods, there is almost no flexibility or ability to quickly supply unanticipated demand. Were the Gabon or South African production to be fortuitously disrupted, about 1.3 to 1.75 million m.t. of contained manganese units per year would be removed from world supply. The Ukraine would have to add 50% to its productive capability to compensate for the deficiency. This is considered highly improbable and would require a long period of equipment buildup.

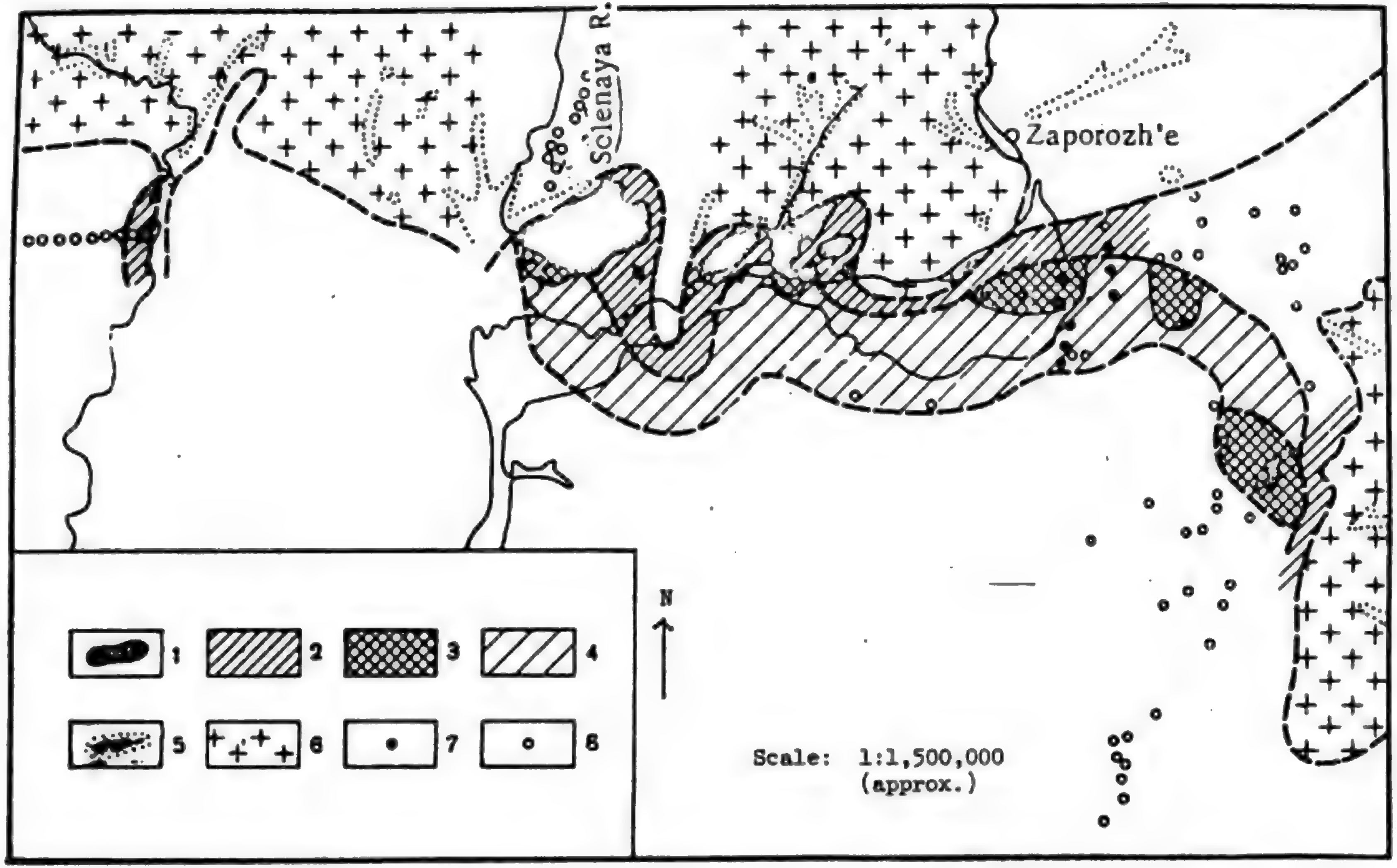


FIGURE A-7. South Ukrainian Manganese Ore Basin (Modified After Sapozhnikov, 1967)

Inferred Distribution of Manganese Ores

1. Definite occurence of oxide ore
2. Inferred oxide ore
3. Definite occurence of carbonate ore
4. Inferred carbonate
5. Crystalline rock outcrops
6. Inferred crystalline basement
7. Boreholes intersected Mn
8. No manganese in holes

A.6.1.2 Georgian Basin - Tchiatura

The Tchiatura basin contains about 9% of USSR economic reserves and accounts for about 28% of the production of contained manganese units in usable concentrate, i.e., about 1.015 million m.t. contained manganese per year.

The best ore was mined 70 years ago, and average concentrate grade has dropped from over 50% manganese to about 40%. About 39% of commercial reserves (balansovye zapasi) are carbonate ore, containing about 23% manganese in the crude state, which is difficult to beneficiate. More than two-thirds of annual production is from a thin, horizontal bed underground. More than 30% of the underground mining is secondary recovery from old stope areas that are difficult and expensive to mine. Reserve analysis suggests about an 18-year remaining life at 1980 production rates. Ore conservation measures include secondary recovery (salvaging ore from early workings), experimental recovery of low-grade manganese from slimes, and optimization of mining.

As in the case of Nikopol', the nature and complexity of the mining/beneficiation operations preclude any substantial near-term rise in concentrate production to palliate a deficiency in world supply if high-grade ore sources such as Gabon or Australia were disrupted. Although there were some ore additions from 1968 to 1972, they are not substantial and one can regard Tchiatura essentially as a source in static production or slow decline.

A.6.1.3 Others

There is insignificant manganese ore production from Kazakhstan, Karadzhal deposits (Atasu) and Karsakpai (Dzhezdinsk) deposits that goes to the Pavlodar ferromanganese production unit. The grade is 20 to 25% manganese and recoverable reserves, in terms of manganese content in these and all other USSR deposits as listed in the synopsis, are relatively insignificant, if indeed economic, as compared to Nikopol' and Tchiatura. They account for only 9% of the total reserve balance, expressed as tons of crude ore, as given (without grade) by Boyarskiy (1975).

There are numerous deposits, occurrences, and resources of manganese in the Soviet Union, none of which is consequential compared to the Nikopol' (Ukraine) and Tchiatura (Georgian SSR) deposits. Because of the importance of the latter two, they are treated at some length and all minor occurrences are summarized in the synoptic Table A-15 at the end of Section A.6. The aggregation of reserve and resource numbers in Tables 3-7 and 3-8 for the deposits other than Nikopol' and Tchiatura is explained in A.6.6.

A.6.2 Nikopol' Manganese Ore Basin

From the standpoint of contained manganese in the usable production, the Nikopol' district in the southern Ukraine rivals South African aggregate production. Nikopol' has been mined since 1889 and is the most important in the world as far as production activity and development.

Geographically, from west to east, the basin consists of six deposits. They are Ingulets (unimportant), from the river of the same name about 50 km south of Krivoi Rog; Vysokopol'e, Novovorontsovka (unimportant); the Nikopol' East and West deposits (important), about 50 km southwest of Zaporozh'e Donetsk, north of the Kakhovka reservoir; and Bol'she Tokmak, 75 km southeast of the same town. The Nikopol' and Bol'she Tokmak are deposits on either side of the Dnieper River. All deposits are served by rail and are within 100 km of Black Sea ports. Had quality and production permitted, they were well situated, competitively, for international trade.

The Nikopol' deposits are covered by large open-pit and underground mines operated by two combines Gorno Obogatitel' Kombinat (mining beneficiation combine) (GOK). The western or Ordzhonikidze Combine operates the following open pits: Bogdanovsky, Shevchenkovskiy, Alekseyevskiy, Zaporozhskiy, Chkalovskiy No. 1, and Severniy (the northern). The eastern district, under the Manganese State Combine, operates Grushevskiy and Basanskiy open pits, together with 18 underground mining operations. Other deposits under the Manganese GOK are the Komintern-Mar'evski, and 4 smaller, mainly oxide deposits, i.e., Zakamenskii, Novoselovskoe Pit, Nikolaevskoe, and Maksimovo-Timoshevskii.

Each combine has washing/concentration plants; altogether there are eight. Ordzhonikidze has three washers and one sinter plant. The Nikopol' manganese ore basin has 82% of all USSR reserves and accounts for about 72% of the usable concentrate. Because many of the operations are similar and because they are essentially all on one ore deposit formation, the descriptions below are generalized.

A.6.2.1 Production & Chemistry

Nikopol' predominates in aggregate USSR production figures which were 9.2 million m.t. of usable concentrate product in 1978. Calculated content of all ore shipped was about 36.2% manganese in 1968, 36.4% in 1969, and has been dropping slightly to 33.8% in 1977. USSR exports of manganese concentrate are declining both in absolute tons and in percentage of total production (see Table A-10: USSR Manganese Ore Export Statistics).

Of about 6.7 million m.t. of usable concentrate from the Nikopol' mines' crude ore production of 14.4 million m.t. in 1978, it is estimated that about 3 million had a grade of over 45% and 3.7 million graded 34%.

TABLE A-10. USSR - MANGANESE ORE PRODUCTION AND EXPORT STATISTICS (THOUSANDS OF m.t.)

	1974	1975	1976	1977	1978
PRODUCTION (CONCENTRATE)	8155	8459	8636	8595	9200
EXPORTS					
Bulgaria	130	136	127	108	78
German D.R.	150	179	185	186	170
Czechoslovakia	329	341	356	320	373
Poland	495	484	482	502	446
Norway	65	57	5	-	-
Sweden	37	26	18	5	-
Japan	194	112	75	110	19
Others	82	86	94	121	100
Total	1482	1411	1342	1352	1186
EXPORTS AS PERCENT PRODUCTION	18.2	16.6	15.5	15.7	12.9

SOURCE: Exports: Ministry of Foreign Trade USSR Foreign Trade Statistical Review, Annual Publication. Published by "Statiskika" Moscos (Ministerstvo Vneshnei Torgovli, Vneshnyaya CCCR, Statisticheskii sbornik, Mockba "Statistika" 1976 and other years)

Because the crude ore varies from oxide to manganese carbonate, there are various crude "ore" and concentrate qualities. All concentrate is high in phosphorus, ranging from 0.18% in carbonate concentrate to 0.25% phosphorus in oxide concentrate. Loss on ignition (LOI) is 6 to 14% for oxide product and 25 to 34% for carbonate concentrate. The phosphorus is in kurskite, a phosphate mineral not eliminated in the wet gravity concentration. All ores are low in iron, giving acceptable manganese-to-iron ratios for ferromanganese production. Silica in oxide concentrate is about 5%, but it ranges from 8 to 17% in "low-grade carbonate." Illustrative, generalized data as to crude ore quality and concentrate grade are as follows:

Crude Ore	% Manganese	% in Manganese Concentrate	% Manganese in Sinter
Low-grade Carbonate	13	22	-
Carbonate	15-17	27	36
Oxide	23-26	39-43	-
Mixed Oxide + Carbonate	11-35	32-35	-

Distribution of crude ore grades in deposits is illustrated in Table A-11.

TABLE A-11: CRUDE ORE GRADE DISTRIBUTION IN SOME DEPOSITS

Nikopol' East (Grushevo-Basanski)

Approximate Percent of Grade Interval	Crude Ore Grade Range % Mn
5	barren
2	13
25.0	13-17
25.0	17-21
16.7	21-25
33.3	25-33
average (approx.)	22

Bol'she Tokmak

2	13
5	13-17
12.5	17-21
50.0	21.25
10.0	25-29
5.0	29-33
10.0	+33
average (approx.)	19

TABLE A-11 (continued)

Komintern-Mar'evski

Approximate Percent of Grade Interval	Crude Ore Grade Range % Mn	Concentrate Grade
5%	13	25
mainly carbonate ore		
10%	13-17	22
10%	17-21	22-25
mixed carbonate/oxide		
40%	21-25	25-34
20%	25-29	34-43
5% mainly oxide	29-33	43-47
10%	+33	+47
average (approx.)	23	

A.6.2.2 Mining

Extraction is an enormous earth-moving operation. All ore up to 1952 was mined underground. To lower cost and increase productivity, open-pit mining using giant complexes of bucket-wheel excavators, draglines, and long conveyors is being used more and more, to stripping depths of 90 m for an ore bed that is generally about 1.5 to 2 m thick, but may be even less than 0.5 m in some places. Strip ratios average 20 m^3 per m.t. of crude ore. Some illustrative thicknesses of mined sections or sections developed for mining are Grushevsko-Basanski, 2.18 m; Bol'she Tokmak, 1.05 m; and Komintern-Mar'evski, about 1.4 m. Orebodies are below minable thickness at the edges, have finite boundaries, and are of irregular form.

Overburden is 97% of all material handled and accounts for 90% of the production cost. Since 1974, Ordzhonikidze GOK (mining/concentrating combine) is all open-pit and productivity is estimated at 2.94 times better than the underground operations, on average. The increasing emphasis on giant bucket-wheel excavators and long belts to strip and move overburden is shown by the following progression:

Year	Percent of all Output	Cubic Meters Handled by Bucket-Wheel
1971	37.4	56,937,200
1972		80,012,700
1973		71,400,000
1974		85,539,200
1975	45.1	90,915,000

Overburden is either green clay up to 15 m thick, or sands of the Sarmatian formation, immediately over the manganese, up to 12 m thick. Ore-bed thickness range is 0.5 to 3.1 m and averages 1.9 m. Beds dip lightly south. Drainage has been a problem. There are 5 water-bearing horizons, of which the upper two have little flow. The third horizon (Lower Sarmatian) has much water, with a hydrostatic head of 15 m. The fourth water horizon is in the ore formation. Daily water flow ranges from 792 to 14,712 m^3. Original drainage concept of water-lowering wells under the pits was abandoned as uneconomic, and replaced by sump pumps handling up to 100 m^3 (25,000 U.S gallons per hour).

Equipment complement for Ordzhonikidze GOK includes 9 large bucket-wheel excavators, 37 walking draglines, 83 shovels, 364 rail cars, and 415 vehicles. Individual pits range from 3 to 7.5 km long and 2 to 4.4 km wide. Transport of crude ore to washing plants is by railway cars BC-80 using electric locomotives type El-1 or steam locomotives TEM-2's. Main conveyor belts are 4 to 4.6 km up to 5.5 km long. Open-pit mining in the Nikopol' Basin increased from 76.5% of all ore in 1971 to 78.6% in 1975.

Yarovoy et al. (1977) furnished the individual pit data shown in Table A-12 to which has been added the calculated crude ore reserves based on the years of life and 1975 crude ore production indicated by Yarovoy.

TABLE A-12. PRODUCTION DATA AND CALCULATED RESERVES (m.t.)

1975

	Stripped Material	Crude Ore	Years' Life	Crude Ore Reserves
Ordzhonikidze GOK				
Bogdanovsky	23,018,800	1,275,700	26	33,168,200
Shevchenkovsky	28,336,700	1,737,600	47	28,336,700
Alekseyev	21,875,100	1,979,700	22	43,553,400
Zaporozhsky	31,245,400	1,983,200	38	75,361,600
Chkalovsky No.1	30,203,500	1,384,300	45	62,316,000
Northern	24,266,400	1,140,000	44	50,160,000
Manganese GOK				
Basanski	16,986,300	713,100	33	23,532,300
Grushevsky	16,697,200	1,138,700	33	37,577,100
	192,629,400	11,352,800	35.9	407,288,800

SOURCE: Yarovoy, et al. (1977)

Average strip thickness is 57.64 m except for Alekseyev (33 m). In 1975, material was handled as follows: 4.9% by rail, 26% by conveyor, 9.2% by truck, 19% to spoil bank with double handling, and 40.8% direct to spoil bank. Average truck haul is about 2.5 km. The spoil angle on stripped material is 17 to 18°, while on material in place the repose angle is 30°. Upper bench slope is 40° and lower 30°. Generally operations run 10 months depending on winter severity, when temperature can reach -13°C. For cultural and recreational uses and for stocking washing plant slimes, 80% of the land is restored. Starting in 1974, 4 million m^3 have been put back at Ordzhonikidze, and 3 km^2 have received slimes at Manganese GOK.

In early 1979, a 400 m long decline of a 22 m^2 section was being driven in a two operating shaft area of Manganese GOK, to raise 1.5 million m.t. of crude ore annually while the shafts were under reconstruction. The Economic Gazette (1979) mentions that to increase work tempo designers have to design access drives for a single shaft of up to 10 km. The cost and productivity history of Ordzhonikidze GOK and Manganese GOK for five years, 1971-1975, are given in Table A-13.

The reason for higher unit cost at Manganese GOK is not immediately apparent since both combines have some pits with a strip ratio of greater than 20:1. However, Basanskiy and Grushevskiy have some of the thinnest ore. Compared to the cost of crude delivered to concentrator (Mamen, 1967), the 1975 cost represents an increase of

3.3% per year, compounded. In 1975, the cost per m.t. of ore after sintering was about $17.30, neglecting recovery losses and cost of beneficiation steps. The low grade and elaborate processing make the product high-cost. Since all ore is mined by a shovel, without selection, and since areas of mining are either filled-in or reclaimed for cultural uses, there is no remaining resource to be reworked later.

TABLE A-13. COST & PRODUCTIVITY HISTORY, 1971-1975

	Rubles per Metric Ton Crude		Productivity (Tons per Year per laborer)	
	Open Pit	Underground	Open Pit	Underground
Ordzhonikidze GOK				
1971	4.89	6.83	2671	908.9
1972	4.86	6.75	2720.6	920.5
1973	4.92	5.82	2822.4	944.9
1974	5.18	4.85	2844.3	708.7
1975	5.50	--	3134.1	--
Manganese GOK				
1971	6.36	7.20	2068.9	961.5
1972	6.55	6.94	2052.4	1021.5
1973	7.33	6.80	2013.7	1063.7
1974	8.06	6.54	1404.9	1134.5
1975	8.75	6.45	1600.1	1179.8

SOURCE: Yarovoy, et al., 1977

A.6.2.3 Beneficiation

Oxide, near-shore ore contains pyrolusite and psilomelane, mixed oxide/carbonate ore has manganite and polypermanganite, and carbonate ore contains calcite, rhodochrosite and manganocalcite. Ore forms are nodules, pisolites, oolites, earthy, and disseminated.

Ore is crushed, screened, washed, and classified, by either jigs or other gravitational devices. Screen oversize is crushed in rolls to 35 mm and again to 3 mm. Fines are treated by electromagnetic separation and the coarse fraction (3 mm) goes to high-intensity magnetic separation and flotation. After dewatering, the product is agglomerated on belt sintering machines.

A.6.2.4 Ore Character

The bed is remarkably persistent laterally, although varying considerably in thickness from 0.5 to 4.5 m where mined. The bed terminates by natural thinning, not by structural complication. Grade decreases south and southwest, down dip, as oxide ore gives way to carbonate.

Regionally, ore is truncated on the north by the shore of the Oligocene sea. The extent of the arcuate band from Nikopol' to Bol'she Tokmak has been fairly well defined by development drilling in the mine areas and regional reconnaissance, which shows where the ore is absent (see Figure A-7).

A.6.2.5 Reserves

The lower Oligocene manganese-bearing sedimentary formations, of the Ukraine, Caucasus, Bulgaria, and Israel in aggregate, probably represent the greatest and most continuous accumulations of manganese in the world, not all of which, because of thinness, chemistry, or other uneconomic factors, are ore. Characteristic features are a thin ore bed of remarkable persistence and low grade, with some diagenetic manganese redistribution. The ores have finite boundaries, with no gradational fall-off in manganese content, that rapidly drop to the Clarke value beyond the edges. The manganese is considered to have been leached under more special alkaline, rather than acid drainage conditions from the source rocks, in a rather warm, humid zone, with tectonic activity, under a high pH and neutral eH environment. The ores have a restricted stratigraphic environment, which in the case of the southern Ukraine was an arcuate band roughly east-west 20 km wide, and interrupted by erosion.

The soluble manganese was deposited in the silts of marine gulfs eroded into the stable basement (whence the finger-shapes pointing south) in the sublittoral zone, where the depth of the sea did not exceed 20 m during the oxide deposition. In the carbonate zone, the depth of sea did not exceed 10 to 20 m. The rather special physico-chemico conditions and the narrow hypsometric zonation are favorable conditions that may not have been general in the world, or in other geological periods. The special conditions resulted in the separation of iron and its deposition away from the manganese, making for good ratio ore occurrences, albeit of low primary grade. It is unlikely that any grade much higher than 20% is undiscovered.

The Nikopol' formations have been extensively studied by Russian authors and the foregoing theories of genesis have been tested by a long period of exploration. In the Nikopol' East area, Sapozhnikov (1970) stated that all the ore is defined in detail and "only a small increase in reserves may result from detailed mapping." Development has been intensive. In the Nikopol' area altogether, there are over 1000 holes, plus the numerous exposures by underground workings and shafts, so that ore quantities are known with a high degree of reliability. For example, on Nikopol' East (Grushevsko-Basanski), development has been by a regular grid of about 250 holes or 20 holes for 7 linear km, i.e., about 3 times as intensive as South African reconnaissance.

Within the limits of the Nikopol' producing area, Baranova et al. (1963) state that the remaining work is to define ore quality with more C_1 reserves and to define the conditions of sedimentation. In Bol'she Tokmak, the aim of continuing work was to identify higher-grade ores. Detailed geological investigations were completed in 1958. Bol'she Tokmak was opened during World War II and explored in detail in 1952 to 1955. Outside the producing areas, the following facts must be weighted in considering whether there is any additional potential. Feodos'ev found the Ingulets (most western occurrence) River outcrop in 1874, but no significant ore has been added at that locality. In 1883, Domger found a manganese outcrop on the Famina Balka, a left tributary of the Solenaya, but it was mined out and there is no significant mining development in this locality. The Bol'she Tokmak was discovered fortuitously when manganese was found in a water well in this easternmost area. Thus, the general extension has been delimited fortuitously over 65 years. In 1947 to 1949, scientific investigation largely replaced happenstance and manganese carbonate was discovered 30 km north of Bol'she Tokmak, in a borehole at Scherbaki. Drilling enlarged the deposits on the basis of a 1949 prediction map. However, drilling did not hit any ore in 56 holes north and south of the Nikopol' area.

Because of the genetic type and the shallowness, prospecting is easy, but it can be assumed that the prospects for additional reserves are not great. The circumstantial evidence of diminishing reserves is found in Sapozhnikov's 1973 statement that the problem "of the gradual decrease in the reserves of rich oxide ores is becoming acute in deposits which have been worked for a long time." Thus, there is no objective, geological evidence that reserves or resources will be greatly extended.

A.6.2.6 Reserve Analysis

Varentsov (1964) states that contained manganese in the Nikopol'-type formation (glauconitic silts and clays of lower Oligocene) of the southern Ukraine, including Nikopol' and Bol'she Tokmak, is 90% of 806 million m.t. contained manganese, which equals 725 million m.t. of manganese. This includes resources and unminable material.

Antropov's (1958) inventory of USSR manganese ore gives 983.9 million m.t. of oxide and carbonate ore in the Nikopol' basin in the A+B+C_1 categories. Boyarskiy's (1975) corresponding Jan. 1, 1971 figure is 985.1, which is reasonably consistent because some minor ore was added to reserves as they were withdrawn. About 50% of the remaining ore, in modern descriptions, is characterized as oxide ore, to which an average crude grade of 28% may be assigned. The carbonate and mixed oxide-carbonate ores probably grade around 17 to 18% manganese. After deduction of production from 1958 to 1978 (210 million m.t.), Nikopol' should contain about 774 million m.t. of crude ore grading 22% manganese or 170 million m.t. contained manganese. Deduction should be made of an unrecoverable 18 million m.t. of contained manganese in the underground ore, thus leaving 152 million m.t. contained recoverable manganese.

Yarovoy et al. (1977) state that the open cast mineable Nikopol' ore is about 60% of all minable ore. Using the Ordzhonikidze and Manganese GOK open-pit, crude ore reserves as 407 million m.t. in 1975, the remaining total ore would be about 688 million, of which about 280 million are to be mined underground. Considering ore mined annually since 1975 at, say, 11.3 million m.t. open-pit and 3.1 million underground, present reserves would be about 375 million of open-pit ore at 100% recoverable and 280 million underground, of which maybe 75% is recoverable. This yields a total crude recoverable of 585 million m.t. grading about 20% manganese (the average of Grushevo-Basanski), i.e., 128 million m.t. contained manganese, before washer losses. The difference between this figure and that of Antropov is about 20%.

It is concluded that Nikopol's 1979 economic, minable ore reserve is about 585 million m.t., grading 22% manganese and containing a recoverable 128 million m.t. manganese before washer losses. Based on manganese recovered in products versus crude ore production to washer, the washer losses are about 20 to 25%. Thus, contained manganese recoverable would be about 103 million m.t. This ore is about two-thirds measured (A+B) and one-third indicated (C_1). The projected lives of the Nikopol' open pits average 31 years. There is a very minor amount of inferred ore, C_2, neglected in the foregoing analysis, because of its relative insignificance. It amounts to 6.8 million tons included in the "reserve balance." If it contains an average 22% manganese, it represents possibly 0.75 million tons of recoverable manganese at an overall yield of 50%.

A.6.2.7 Resources

In the Nikopol' mining areas there are no resources since all material is taken.

The measured reserves of Nikopol' and the resources of Bol'she Tokmak, as given in various Soviet references, Antropov (1958) and Boyarskiy (1975), together represent about 530 million m.t. of contained manganese before any recovery factors. This is about 200 million m.t. less than Varentsov's (1964) aggregate figure. Consequently, it must be presumed that elsewhere either thin, discontinuous, or otherwise uneconomic material exists, containing 200 million m.t. of manganese. It is believed this must be a subeconomic resource, probably less than half recoverable.

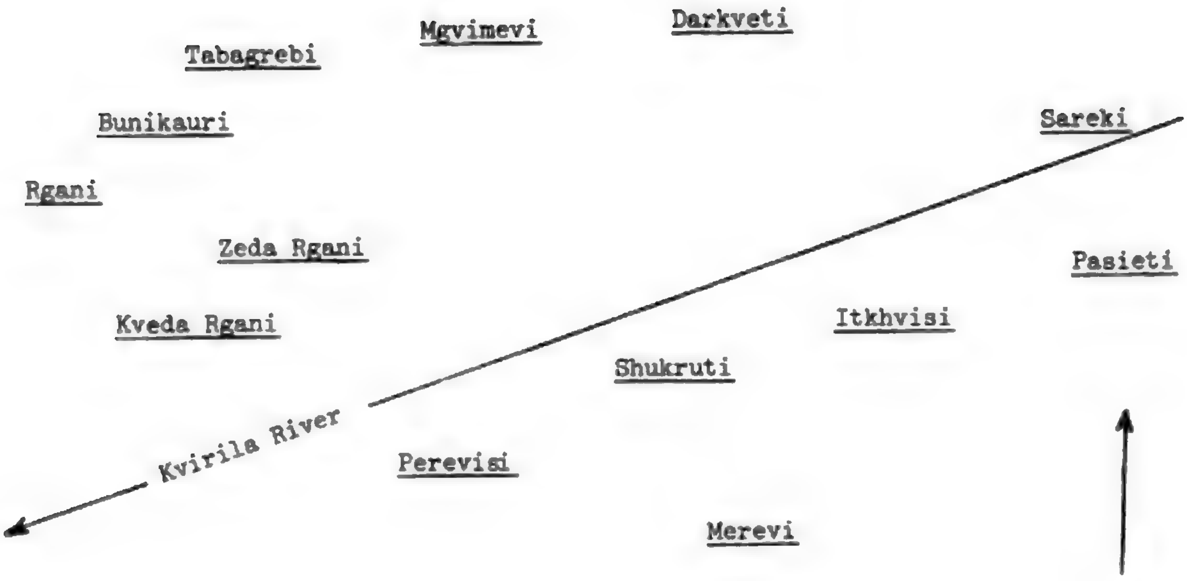
A.6.2.8 Bol'she Tokmak

The ore of Bol'she Tokmak, the sister deposit to Nikopol' on the east side of the Dniepier, is 20% lower grade than Nikopol' (average 18.53% manganese) and contain 90% carbonate ore and only 10% oxide ore; Nikopol' contains 50% oxide ore and thus gives a better average-grade product. Although Bol'she Tokmak is listed as economic ore and thus in the "reserve balance," by western standards, considering the high strip ratio and difficult concentration, it would be marginally economic. If all production had to come from Bol'she Tokmak when Nikopol' is exhausted, the average concentrate grade would be nearer 31.0% manganese than the present 40%.

Antropov (1958) listed Bol'she Tokmak reserves as of 1958 in $A+B+C_1$ at 611 million m.t. crude, whereas the corresponding 1 January 1974 figure of Boyarskiy (1975) is 1.109 billion m.t. without any grade specified. Assuming the same ratio of open-pit to underground as at Nikopol', the recoverable crude ore reserves at Bol'she Tokmak would be about 990 million m.t. with 183 million m.t. of manganese before washer and other losses, or 146 million m.t. recoverable manganese. It should be noted, however, that only 13.5% is A+B, and the balance is C_1 indicated. Boyarskiy's C_2 is 307 million m.t. and, assuming the same relationships, would yield 51 million m.t. manganese before washer and other losses, or 40 million m.t. recoverable manganese.

A.6.3 Tchiatura

The Tchiatura manganese ore region, on both sides of the Kvirila River, in the Georgian SSR, is the oldest significant manganese ore-producing region in the world. The area is about 180 km by rail east of Poti or 170 km east of Batum, both Black Sea ports. Rail loading stations are Darkveti and Tchiatura. Deposits are in the Tchiatura and Sachkherst administrative districts on the south slope of the Rachinsk Mountains. Elevations of the upland are 400 to 800 m and local relief is 250 m. The nearly horizontal manganese ore-bearing layers are overlain by a cover of 20 m in the southwest, increasing to 70 to 80 m in the northeast. The south-west flowing Kvirila River divides the principal manganese occurrences into a northwestern group (which from west to east includes: Rgani, Kveda Rgani, Bunikauri, Zeda Rgani, Tabagrebi, Mgvimevi, Darkeveti and Sareki) and a southeastern group (which from west to east includes: Perevisi, Shukruti, Merevi, Itkhvisi and Pasieti). These occur in an area approximately 12 km east-west and 11 km north-south, and can be shown diagrammatically as follows:



Tchiatura Diagrammatic Location Map

A.6.3.1 General and History

Discovered fortuitously in 1846 by outcrop of the manganese beds above the Kvirila Valley, production started in 1879 (1,000 m.t.). Up to 1900, many individual, small adit operations contributed significant tonnage and much good ore was thrown away. From 1900 to 1925, Tchiatura contributed from 20 to 40% of world production. In 1913, production was already 1,066,600 m.t., mostly hand-mined. It fell drastically during the short-lived Republic of Georgia, Caucasus to 25,520 m.t. in 1921 and rose again to about 500,000 m.t. in 1924. After incorporation into the Soviet Union, the domestic owners were nationalized immediately, but the foreign owners were not. From 1925 to 1928 the government leased the mines to the A. Harriman group, with the understanding that the narrow-gauge railway system was to be upgraded.

All early development was by adits, which reached 340 in 136 localities on the bed. The number of companies ranged from 7 to 260. In 1923 there were already 31 washing plants, with an aggregate capacity of 810,000 m.t. Washing yield in 1924 was 60 to 65%. No. 1 high-grade ore assayed 54.9% Mn, 1.5% Fe and No. 2 assayed 50% Mn and 1.0% Fe, both with about 3.3% SiO_2 and 0.19% P. Moisture was 8%. Considerable material that would now be considered low-grade or resources was wasted.

Tchiatura has been completely explored and is now in decline. Ore conservation measures include secondary recovery, i.e., salvaging ore from early workings (see below); experimental recovery of low-grade manganese from slimes; and optimization of mining.

A.6.3.2 Production and Chemistry

About 7.5 million m.t. of crude ore annually, mined mainly from underground operations, produce about 2.5 million tons of concentrate, of which about two-thirds contain 48.7% manganese and one-third about 25.6% manganese. The higher-grade ores are mainly oxide, the lower mainly carbonate which does not respond to mechanical beneficiation with any practical ease.

The concentration plants produce Grade I (48% Mn) and Grade IV (carbonate at about 25% Mn), and also dioxide Type I at 89% MnO_2 and Type II at not less than 84% MnO_2. This dioxide is used as a better-grade raw material for activated pyrolusite and oxidizing purposes. Some is exported. It is believed about 20% of Tchiatura good product is exported to countries with centrally planned economies. Washed Ore Grade I is used for ferro- and silicomanganese manufacture. Type IV is used for blast furnace additions to the hot metal, and 40% can be blended in the ferromanganese burden. Phosphorus is generally 0.17% in products, which is rather high compared to ores in western commerce. Illustrative chemistry of some ores may be found in Table A-14 (Avaliani, 1958).

A.6.3.3 Mining

Ore layers dip 10 to 12° and are mainly mined underground by pillar and room off long-drives in from the flanks of highlands. Aggregate ore thickness is 2 to 3 m, in individual beds of 0.2 to 1 m. There are up to 25 ore-bearing layers, but more commonly 3 to 18, and these are interlayered with sands and clays to a maximum of 1 m, but more commonly 0.3 m. The lower layers have the most commercial significance. Roof is Maikop clays; floor and sublayers are quartz sands and sandstone.

Northeastward, i.e., toward Darkveti, Sareki, and Pasieti, the thickness of ore beds decreases, the oxide ores are gradually replaced by carbonates, and the thickness of interlayers increases. Overburden increases from 20 m to 70-80 m. The ore distribution map shows that the better grade (+25% manganese) occurs in the western highlands such as Shukruti, Mgvimevi, Perevisi, Rgani, etc. This area has been preferentially mined. The eastern highlands, Itkhvisi, Darkveti, Pasieti, and Sareki, have only from 10 to 20% manganese and, considering the underground mining, might be just as easily considered protore, i.e., resource rather than ore. The fact that secondary recovery is in progress in the western highlands (Rgani, Zeda Rgani, TABLE A-14. ANALYSES OF ORE AND PRODUCTS (wt. % dry)

Type	Mn	Fe	P	S	SiO_2	Al_2O_3	CaO	MgO	H_2O
Disseminated oolitic	47.50	1.07	0.18	0.31	17.41	1.29	0.81	0.37	n.a.
Brown "belta"	47.30	0.10	0.16	n.a.	8.42	0.80	0.32	2.00	8.41
Black "belta"	53.21	1.40	n.a.	0.20	7.97	1.99	1.49	n.a.	1.71
Carbonate ore mine 26	23.39	1.20	n.a.	0.44	7.31	1.47	22.65	n.a.	1.79
Oxidized carb. ore conc. Plant	43.32	1.40	n.a.	0.23	11.07	4.01	5.46	n.a.	7.73
No. 18 "Plast"	45-58	0.5-1	0.1-0.18	n.a.	3-18	1-3	0.5-1	n.a.	2-3
Classifier fines No. 11	24.32	2.30	0.25	0.04	39.97	7.86	2.33	0.99	n.a.
Carbonate Ore (Dark-Veti)	22.22	0.58	n.d.	n.a.	3.22	1.04	5.12	0.36	n.a.

n.a. = not available
n.d. = not detected

Source: Avaliani, 1958

Shukruti, Perevisi, Itkhvisi, and Mgvimevi) suggests that salvaging this higher oxide ore is still more attractive than opening new mines in carbonate to the east.

Old mined and filled areas are redrilled for assessment. The cutoff for secondary recovery is a minimum of 0.8 m and more than 15% manganese. Average thickness in actively-mined secondary recovery areas is 1.56 to 3.25 m, and manganese ranges from 23.5 to 41.6%. The grade in newly worked areas is significantly lower, i.e., 23 to 29.5% manganese.

Area to be robbed is divided into panels of 200 m by 25 to 30 m, with crosscuts between ventilation drives. Pillars are robbed by drifts 3 to 4 m wide and 15 to 17 m long. Drift height corresponds to ore thickness. Ore is broken with jackhammers, as a rule, and there is some hand-sorting when loading cars. Roof support is wood prop with partial organ-pipe support set at 0.3 to 0.5 m. Where roof caving must be induced, it is affected with jacks.

In 1974 one ton of production from secondary recovery cost 50% more than conventional primary recovery. However, because of better ore quality in old workings, one ton of concentrate costs only 25% more than new ore; this justifies the secondary recovery. Of this total production, 67% is underground of which more than 30% is now secondary. Kalandadze et al. (1977) state that "technico-economic trials of secondary recovery show a substantial influence on the economy of the combine and the task cannot be postponed."

Two modes of recovery depend on the ore type.

(1) In the oxide or the oxidized ore only, breaking with a jackhammer is easy, especially when the ore has deteriorated so that the pillars can be preferentially crushed. These areas were worked from 1936 to 1940 and old props are rare. Workings are cut in places by roof falls and "zhgali." They are mined by a cutter combine on treads and by a pneumatic hammer.

(2) Poorly oxidized ore and carbonate ore, with significant included rocks, generally have old props. Because of the collapse of primary workings, the ore breaks down into oversize. It is mined by blast-hole drilling and loading machines. Shift advance is 2 m. The aforementioned review states that worker productivity is up 50% and cost down 9%. Mechanical loading and combine breakage were tested at Akhali and Itkhvisi. Reduced labor lowered mining cost 30% to 1.5 rubles per m.t. in 1977.

A.6.3.4 Beneficiation

Multiple ore types have different responses to beneficiation. In the local terminology, these are as follows:

1. Disseminated, hard, oolitic ore: 1 to 20 mm in diameter, containing psilomelane, pyrolusite, and manganite.
2. Brown belta: earthy, oxidized manganite, contains considerable moisture; clay-like, generally fine oolites 1 to 1.5 mm cemented by opalo-sandy material.
3. Black belta: developed above brown belta in near-surface conditions; soft, sooty, smudgy, digitated, oxidized manganite and pyrolusite. Contains less moisture and less peroxide than brown belta.
4. Plast: hard, massive ore containing pyrolusite and psilomelane.
5. Satshrili: similar to disseminated oolitic, but encloses angular pieces of hard ore ("plast").
6. Zhgali: variety of disseminated oolitic, with tougher cement, but can be broken with a jackhammer; is amenable to beneficiation. Contains 0.1 to 1 mm pyrolusite, psilomelane, and rancieite.
7. Mtsvari: hard, calcitized ore, with some hydrothermal adjuncts; contains pyrolusite, psilomelane, and rancieite (calcian psilomelane).
8. Carbonate ore: either massive or porous; containing manganocalcite, calcium rhodochrosite, calcite, opal, pyrite, and marcasite (which contribute sulfur); 39% of the reserve balance.

The first seven types are primary oxide ore with up to 80% MnO_2. However, much of the oxide ore is soft (belta) and goes to slimes in beneficiation. Collectively, these ore types account for 47% of the reserve balance. Easily beneficiatable ores, called washable, are granular plast, satshrili, and zhgali among the oxide ores and comprise about half of reserves.

Ores that are difficult to beneficiate are used raw, such as carbonate ore, mtsvari, belta, and manganese-bearing sands. The last resulted from infiltration of leached manganese with opal, especially in the eastern part of the deposit, and manganese rarely reaches 25%.

There is also oxidized-carbonate ore, representing 18% of total reserves, developed by weathering of the manganese formations, mainly vernadite, psilomelane, and rancieite, with manganese in the 30 to 35% range. It does not respond to mechanical beneficiation, and extensive tests to use it in the raw state show application on a 1:1 ratio basis with Grade I oxide, to make standard ferromanganese or silicomanganese, or to use in blast furnace additions. Some illustrative analyses of ores and products are shown in Table A-14.

Beneficiation steps include screening, wet grinding, washing, classifying, and flotation. Recently, as a conservation measure, there has been considerable work on recovery of manganese from slimes. Of slime ore per year, 25 to 30% or 1.3 million m.t. follow the clay fraction in processing and average 8 to 12% manganese. Of this, 910,000 m.t. come from the central washer.

By flotation there is the possibility of separating manganese from the clay to give an off-grade concentrate with 15 to 20% manganese. Ordinarily, washer losses are 45 to 50% of the metal. Froth flotation of the sand fraction recovers 35 to 40% of the manganese in that fraction. Flocculation tests gave a discharge of 4 to 8 kg per m.t. of slimes. Manganese recovery in the plus 0.02 μm was 45 to 55%. Polygradient magnetic separation gave up to 70% manganese recovery in the 0.04 to 0.05 μm fraction. Magnetic flotation was very effective on the below 0.005 μm fraction and gave overflow solids with 5 to 12% manganese. The elaborate tests concluded that it was possible to agglomerate the clay fraction in a magnetic field and float the aggregate at the moment of formation of the aggregates. This was considered to have more future application than flotation alone.

The extraordinarily extensive efforts for recovery of rather modest amounts of the various fractions indicate the concern for conservation. However, the resulting products are extremely low grade (8 to 10% manganese) and would be a resource elsewhere.

A.6.3.5 Reserves

The remarks on Nikopol' ore character and persistence also apply to Tchiatura, which is geologically similar except for the complexity of its ore beds. The ore beds had already been developed by 340 adits at 136 localities as early as the 1920's. Under the Socialist government, geology was mapped by Betekhtin in 1936, and there was a drill campaign in 1940 on the peripheral parts of the deposits. All early observation was directed to the oxide ore, but the Georgian Geological Administration started investigating carbonate ore as to structure, quality, and reserves in 1934. Further drill-hole development has occurred by the drilling necessary to assess old mined areas for secondary recovery. Boyarskiy (1975) shows an increase in reserves from 1968 to 1971 of from about 150 million to 217 million m.t. crude ore. The oxide ore peters out in the northeast and gives way to carbonate. The ore-bearing formation is folded up and eroded out to the north and faulted out to the south. By 1950 to 1953 the "economic ore" had been contoured by 120 km of underground drives, trenches, openings, and 600 boreholes. It is concluded that the possibilities for significant additions to the Tchiatura basin are very limited. Examination of the rest of Georgia has disclosed numerous small showings and deposits, but in aggregate they have not added 5% to the Tchiatura basin reserves.

A.6.3.6 Reserve Analysis

Three reserve estimates made in 1924 (Zereteli, 1925), presumably oriented toward assessment of high-grade oxide ore, were consistent within 25%. They are listed below.

1. Kotsovski: 7 billion poods,* i.e., 112 million m.t., with about 58 million tons of contained manganese. (*Pood = 36.11 pounds.)
2. By local engineer: 14 billion poods, which after washing (recovery 53.5%) would yield 125 million m.t., about 65 million m.t. of contained manganese.
3. By Dekonosishvili: 13.4 billion poods in place, which, after allowing for ore already mined and for recovery, would yield 146 million m.t. or about 75 million m.t. of contained manganese.

Varentsov (1964) gave Tchiatura's contained manganese content as 54 million m.t. This included presumably all the manganese known at that time, whether mined out or resource material. However, it could not have included the 1968 to 1971 additions that, on the basis of a weighted average crude ore grade of 24.5% manganese, would raise the contained manganese to 70 million m.t. It is noteworthy how concordant are the foregoing total manganese content estimates.

The assessment as of 1 January 1980 assumes that while weighted average grade is 24.5% manganese, current average mining grade (carbonate and oxide) is about 30% manganese. This results in a calculated process recovery of about 47%, which does not appear unduly pessimistic in view of Barskii et al. (1977) data that intimate washer losses ordinarily are 45 to 50%.

Boyarskiy (1975) gives 1 January 1971 Tchiatura reserves as 218 million m.t. which after deduction of 1971 to 1979 production, estimated at 63 million, leaves 155 million m.t. crude ore (containing 38 million m.t. manganese). Assuming 75% underground mining at 70% recovery and 25% open-pit at 100% recovery, recoverable reserves as of 1 January 1980 would be about 120 million m.t. crude ore, or about 15 years' life at the recent rate of crude ore production. The contained manganese would be 29 million m.t. and after process losses, about 14.7 million m.t. manganese recoverable.

The C_2 ore was 13 million m.t. which presumably would grade no higher than the mean of 24.5% manganese and possibly less. On the same bases, this would be equivalent to 10.5 million extractable tons containing 2.5 million tons of manganese, or about 1.25 million additional recoverable tons of manganese after process losses.

It is conlcuded that Tchiatura has remaining in place reserves, of all categories, totalling 168 million tons, of which 130.5 million are extractable tons, good for about 17 years. They contain about 31.5 million tons manganese, of which about 16 million m.t. would be recovered.

A.6.3.7 Tchiatura Resources

As mentioned under beneficiation, if industrial recovery of manganese from slimes were fully applied, about 130,000 m.t. of contained manganese in the slimes might yield 50,000 m.t. annually of off-grade concentrate grading 15 to 20% manganese. This resource might add another 1 million m.t. of contained recoverable manganese until mine exhaustion. In view of the complexity of separation steps, the cost must be considered high and this would be a subeconomic resource.

A.6.4 Nikopol' Manganese Ore Basin

A.6.4.1 Ingulets

Manganese oxide concretionary ore in a host rock of clayey, silty carbonate, lies unconformably on lower Kharkov sands, west of the Ingulets River. The deposits are similar geographically to the main Nikopol' Basin and have a slight southerly dip. The area has been eroded, exposing pre-Cambrian crystalline rocks; the 10 small deposits are considered erosional remnants. The area has been known since 1874 and was described in 1961 by Shnyukov as having some practical significance. The largest orebody is 1,650 m x 800 m wide. Others are several hundred meters wide or long. Maximum ore thickness is 3.9 m but the common range is 0.5 to 1.5 m.

Ore is 50% concretionary, 5 to 10 cm in diameter, with a manganese range from 10.4 to 35.26%. More typical averages for 9 small deposits are 14 to 26%. Phosphorus is high at 0.2 to 0.3%. Iron is less than 1%. Although the deposits are oxide ore, the size suggests that they have no present, practical significance, but represent a resource of about 2 million tons of 20% manganese. However, Baranova et al. (1963) suggest it is worth paying attention to the interfluvial region Ingulets-Bazavluk.

A.6.5 Krivoi Rog Iron Ore Basin

This area is west of Shirokoe Village, about 5 to 10 km south of Ingulets. Although iron ore was first described in 1781, and later mined from 1946 to 1959, exploration for manganese was not done until much later. Therefore, the erroneous opinion subsisted that accessory manganese was uneconomic and had low potential. However, when the iron ore was opened up in the southern pit, Skelevtka, an area of about 1 km^2 was recognized as having manganese ores with overall reserves of several million tons. While drilling the limonite of southern Skelevtka, 22,000 tons of manganiferous ore with 22% manganese were identified. The unenriched ore was successfully used in a blast furnace addition and thus obtained some "positive industrial evaluation."

Two types of manganese occurrence are described. One is in the vicinity of the southern Skelevtka open pit. It is a manganese-bearing layer, geologically similar to Nikopol', and underlain by greenish Upper Eocene clays and yellow iron ores. It is overlain by the apple-green Oligocene clays (Kharkov belt) and Sarmatian marls. Manganese ranges from 8 to 33%. There is oolitic pyrolusite up to 20 mm and friable and porous manganite. Some ore is concretionary, up to 350 mm in diameter. The ratio of ore to clayey matter is 1:1 to 1:2. The layer ranges from 0.5 to 4 m thick and the manganite part up to 1 m. The ore is mainly oxide, without notable carbonate, but also contains psilomelane.

The NIGRI (Scientific Research Institute of Geological Survey) Krivbass laboratory, in 1956, easily upgraded the above material with no crushing, by washing, screening, and classifying, to a concentrate grade of 40 to 44% manganese. With heavy medium and flotation they obtained 49 to 50% manganese.

The second type is other Mn-bearing ore lenses which stretch longitudinally, almost N-S, on both sides of the Likhmanov crest of ancient crystalline schists. These areas aggregate about 8.4 km^2 and were they 2 m thick, the potential could be around 50 million tons of 20% Mn. Natarov, writing in 1961, noted the considerable areal development and considered these prospects exploitable in the near future because: they are near a branch of the Stalin railway (Nikolo-Kozel'sk Station), with existing infrastructure and depth is only 12 to 35 m, thus permitting open pit operations.

In the absence of further information the Krivoi Rog Mn occurrences are considered a resource, but quantified with a 50% chance of error.

A.6.6 Other Reserves and Resources in Tables 3-7 and 3-8

For the other minor reserves and resources in the USSR the aggregate numbers in Tables 3-7 and 3-8 were obtained in part by using Boyarskiy's (1975) Table of Reserve Balance for manganese ore in the USSR (p. 34). A+B were considered measured reserves, and C_1 inferred reserves, obtained by subtraction of A+B from the A+B+C_1 given by Boyarskiy. Boyarskiy gave no grade, but these were derived and averaged from other descriptions in the references (see also the Synoptic Tables). Although C_2 material is included by Boyarskiy under reserves as concerns the Far East (Khabarovsk) and Karaganda Oblast in Kazakhstan, these were considered a hypothetical resource because of uncertainties, small size, remoteness, etc. A mining recovery of 65 to 70% was generally assumed, and a treatment recovery of 80% for oxide ore and 50% on carbonate ore.

The submarginal resources in Table 3-8 refer to crude ore recoverable manganese of some of the more significant occurrences in the synoptic Table A-15. The derivation follows (modified after Boyarskiy, 1975):

TABLE A-15. Synopsis of Significant USSR Manganese Occurrences

Type or Name of Occurrence	Mn	SiO_2	P	Fe	Mining Character	Persistence Character	Remarks
South Ukrainian Oligocene Basin (Nikopol, Bol'shoi Tokmaksk, Inguletsk, Krivoi Rog, Khoshchevatsk)	(Carb. Ore) 15.81-31.32 (av. 23.73) (Crude)	13.2-54.8	.008-0.63 (av. .09)	0.48-5.10 (av. 1.31)	Variable thickness, 0-4.5 m.; average 2.0-3.5 m. Ore zone contours are traced by natural (non-Tectonic) thinning out. Grade decreases S & SW down-dip. Phos present in Kurskite not eliminated by wet gravity conc. Swelling of bentonitic clay in roof requires 2-300% overbreak in places.	"At the present time only the relatively thicker parts of the ore development are preserved". Erosion of oxide ore, weathering of carbonate ore. Erosion reduced thickness of ore (at Gr.-Basanskii). Ore truncated on N. by shore of Oligocene Sea. Narrow-stratigraphic zone. Ore limited to definite hypsometric level in depressions in crystalline basement. Oxide ore gives place to carbonate going S&SW. Mn increases away from shoreline and then decreases again.	Varentsov says contained Mn in fm. is 720 M.T. Largest contained Mn. "Post-oligocene erosion essentially transgressed the primary character of the spreading of Mn ore sedimentation." Nikopol ore 50% oxide, 50% carbonate; Bol'she Tokmaksk 92% carbonate, 8% oxide; Shkmersk: 80% carb.; 20% oxidized; CO_2 = 32.4 av. Arcuate band up to 20 km wide.
	(Clayey Carb. Ore 19.5						
	B. Tokmaksk 18.53						
	Grushevska-Basanskii Open Pit 22.45						
	Oxide ore (Crude) 32.39	12.3-76.2	.07-.64	.3-7.3			
	Oxide ore (Conc.) 43	4.3-47	(av. .21)				
	"Low grade ore" 13	(4-13) in manganite)	.14-.43 (av. .24)	.67-3.2			
	"Low grade Conc." 22	8.4-18.2 (pryolusite)					Additional Chemistry:
	Carb. ore (Conc.) 27	–	.18-.24				Concentrates: Oxide / Carb. Alkalies .39-2.74 / .04-1.02 TiO_2 (in manganite) .1-.18 / .06-.19 Al_2O_3 1.01-5.91 / .99-6.78 CaO+Mgo .94-12.76(?) / 9.7-16 ? SO_3 (S=0.05) .1-.35 / .2-.32 LOI 6-14 / 25-34
	"Polypermanganite" ore 25-48 (av. 35.32)		0.11-.09 (av. .03	0.45-2.40 (av. 1.43			Org. 0-.3 (av. 0.12); CO_2 0-2.86 (av. 1.02); Cu 15 ppm-125 ppm (av. 48.1); Ni 70 ppm-352 ppm (av. 191); Co 6 ppm-146 ppm (av. 71.4); U 6 ppm-200 ppm (av. 81.4); Cr 0-20 ppm (av. 11); CaO 2.38-6.70.

TABLE A-15 (continued)

Type or Name of Occurrence	Mn		SiO_2	P	Fe	Mining Character	Persistence Character	Remarks
GEORGIAN SSR								
Caucasus	OXIDE							
Tchiatura	Oolitic	34-55	1-2 gen.	.001-.2		"Several cm. to 1 m. or more" thick. Underground dip 4-6°NE in some places.	Barren, sandy carb. interlayers complicate ores in E&NE. Oxide ore replaced by carbonate to NE. Lensy. Also replaced by ss. & clay. "Thickest Mn ore occurs in irregular and karst surfaces of ls." "It seems that most of the Mn sediments have now been eroded."	Ni up to .23% generally .07-.15 in oxide ores. Ni .1% gen. in carbonate ore. CaO+MgO in carb. ores = 5-33. Co&Ni higher in west. Cont. Mn in formation = 24,000,000 MT. Where ore has >15% SiO^2, it is uneconomic. This is "almost half of the reserve."
	"Satskhrili"	34.1						
	"Plasti"	33-52						
	Black "Bel'ta"	50						
(Shkmersk, Chkhari-Adznametsk, Mayakovsk, Kvena-Tkotsa)	Carbonate	12-22	.3-3.2	.008-.58	.26-1.38			
NORTHERN URALS								
("Midnight") Polunachnoe, New-Berezovsk, Marsyatskoe, Iudel' and Others* Yuzhnaya Mine (over 200 Km)		17.51-21.92	17.98-33.90	0.1-0.3	3.26-6.57	Nearly horizontal–powdery section faulted vertically; fine grained. Depth: surface to 100-300 m. Barren intercalations in ore fm. 0.1 m - 0.2 m to "several meters."	Along strike and down-dip orebodies irregularly replaced by sandy-clayey deposits. "Oxidized ores in deposits of the basin have limited extension; to a great degree they have been exhausted."	Aggregate Mn-carbonate reserves @ 21.2% in N. Urals Mn-ore basin are about 50,000,000 T inferred 100,000,000 MT. "Beneficiation tests on carbonate show possibility of high-grade Mn concentrates for smelting Fe-Mn and Si-Mn." Fifteen "deposits" in aggregate contain 10,000,000 MT Mn. Cont. Mn ore in Mn-formation = 28,000,000 MT Mn. 3 km strike. Open cut, shaft No. 5 worked in World War II <40 m deep. North Quarry: lumpy porous oxide; primary oxide finebedded pyrolusite; 1 layer 1.75 m Mn-Carb. Aggregate 4 m Carb. Only Midnight deposit and New Berezovsk have oxide. Sed. Carb. and subseq. oxidation. Calcium rhodochrosite mangano-calcite and oligonite.
CENTRAL URALS								
Ulutelyaksk								Reserves of Mn-bearing limestones with an avg. Mn content of 10% estimated at 8-10 million tons.
Upper Mn-bearing layer		6-9	7-9	CaO 36-39		Lower Mn layer has 30-40 m. of overburden		
Lower Mn-bearing layer		2-3	10-15	CaO 31-36			Up to 1 m. thick	

Western Part (upper layer)		3-9.47	8-12.9	CaO 33.6-44.6			4.3-7.7 m. thick w/areal extent of 4.5 km^2.	Individual layers may contain 12-18% Mn. "These limestones may be used in melting of steel in Martin open hearths as basis Mn flux, and also in production of silico-spiegel and spiegel."
SOUTHERN URALS								
Primagnitogorsk Group Niazhulovsk Yalimbutovsk Mamilya Falzulunsk & other deposits						The richer Mn capping near Mt. Magnitogorsk mined out during WW II.	Tightly folded and faulted. Mn-bearing horizons in sheets & lenses with limited areal extent 300-500 plus meters. Thickness ore horizons from a few cm to 4-5 m.	Remaining reserves of silicate ores estimated at 3 million tons. Lack of uniformity, small extent, low grades preclude development of the remaining reserves.
Silicate Ores		15-25	45-52	.02-.05	CaO 5-7			Present in the uppermost weathering zone but mined out during WW II.
Oxide Ores		35-50	up to 5	<.1	–			
SOUTHERN URALS								
Akkermanovsk Deposit								Considered to be a sedimentary-volcanic of porphyry series type of deposit of Devonian Age. The reserves of metallic manganese occurring as ore are small. In USSR publications, the reserves are classified lower than general geologic; i.e. remaining non-economic reserves.
Kusimov Deposit		31.6-45	11.5-45	<0.01	1.5-7.5 (Fe_2O_3)	Mainly underground, sheep dip. Thickness several cm to 4-5 m. Average 1-2 m.	Faulted, rapid thickness changes high grade ore lense-like and discontinuous along shore.	Mined during WW II. Trace elements, not above Clarke values. Silicates, oxides and carbonates.
	Blocks	33-37						

TABLE A-15 (continued)

Type or Name of Occurrence	Mn	SiO_2	P	Fe	Mining Character	Persistence Character	Remarks
KAZAKH SSR							
Central Kazakhstan							
Atasu Group							
Karazhal Deposit							
WESTERN	21.15	18.04	0.018	6.04	3-4 Mn horizons 1-3 m. or 10-20 m. Underground min. Dips 30-45°S. Folded. Traced 6 km. along strike and 1,500 m downdip. Complex structure.	In central area, decreases to 0.5 m and wedges out. Mn2 layer less persistent Mn4 layer is lensy. Grades laterally to Fe-Mn-siliceous Carb. Rx and to ore-free ls. Contack w/Rx. sharp—i.e. no grade gradation.	Psilomelane, Mn-calcite; Mn siderite, rare rhodochrosite, rhodomite, 3-10%; tephroite, bustamite. Production started '56. S 0.31. Braunite, hausmanite, jacobsite, no U or As. 60 million MT reserve; oxide ore 25.6% Mn.
EASTERN	27.20	16.20	0.032	4.60	1-2 m thick; 2.5 km strike; 250-400 m downdip.	Wedges out along strike and downdip.	S 0.16; 6% Al^2O_3; 10-12% CaO; H_2O 8-10%. Mn ore goes to Pavlodar Fe-Mn prod. unit. Carb. ore gradually replaces oxide ore on dip slope. Oxide ore close to littoral zone. 18 million MT; no hope whatever for increase.
SOUTHERN							0.2 million MT.
NORTHERN	36.0				0.3-1.5 m. thick—Extends 450 m along strike.	Wedges out.	"Thoroughly investigated". Reserves 130,000 MT!!
Bol'shoi Ktai	23.31	17.87	0.10	12.38			4.2 million MT
Shrednii Ktai	37.0						0.4 million MT
Malyi Ktai	36.0	14.0	0.03	5.5			0.2 million MT
Dzhumart	24.0						4.0 million MT
Dzhairem							–
Ushkatyn I							0.5 million MT
II							–
III	29.0	–	–	2.1	Dips 75°E. Up to 50 m ore zone Fe-Mn beds & ls. 1000-1200 m strike; 400 m downdip.	More Fe, less Mn to north. Tectonic dislocation on eastern flank.	30 million MT
Kamys	24.3	–	–	3.0			3 million MT
Tamara							–

Ataika							–
Other Deposits							10 million MT
							122 million MT
					Karazhal Characteristics: Mn replaces Fe downdip. Irregular contents of Fe, Mn, SiO_2 in various parts of ores. In Mn ores oxides alternate w/predominant carbonates. Upper horizon almost exclusively Mn oxide. Some hydrothermal activity–traces of other metals Pb, Zn, Cu, Co, Ni. Metamorphosed, non-lagoonal. Ore-bearing seds. replaced in all directions by normal marine carb. Rx. Hydrothermal: ore-bearing injections in sea close to deep-seated fault zones. Then block movement in basement; geniculate flexures; baritization.		
Karsakpai Group Dzhezdinsk	braunite 25% Mn psilomelane-pyrolusite 14% Mn					2.5 Km^2 platform with dome-like structure.	Mn ores act as SS and conglomerate cement; consist basically of braunite but in the oxidation zone of psilomelane and pyrolusite.
Promezhutochnoe Naizatasskoe & Others							
Mangyshlak Deposit 200 km east of Fort Shevchenko	Carbonate: Oxide Ore: Conc. av. Crude Ore av. Sartagan area av. Chakyrgan area av.	15.96-22.60 3.84-46.90 12 5.74 2.6 (Crude) 6.8 (Crude)	0-1.69 0-1.91 av. 0.075	1.28-3.95 1.40-6.34 av. 3.04	Ore-horizon 0.8 m. thick. Ore-horizon lensy. "Thickness and chemistry definitely irregular."	Significant Mn concentrations localized in relatively limited area (50 km^2) of an N. edge of Chakyrgan syncline. N. part of deposit is Mn hydroxide; further S. mixed oxide and carbonate; still further S. only carb. "Accumulation of economic Mn-ore differs from embryonic mineralization by its high Mn-content (20% or more.)"	Lower Oligocene quartz-glauconite sandy-clay formation. Oxide ore: pyrolusite; manganite; psilomelane-wad; Criptomelane, todorokite, vernadite. Mn 5-6 to 10% carbonate-Mn ores = > 30,000,000 T–carb. ore; manganocalcite rhodochrosite. Other chemistry: SO_3 .15-1.4; Carbonate Ore; CO_2 6.40-31.34; Corg. 0.14-0.39; V 22-83 ppm; Cr 12-44 ppm; Ni 14-82 ppm; Co 0-10 ppm; Cu 3-116 ppm. Oxide Ore: Co_2 0-74; Corg. 0-0.68; U 22-157; Cr 0-50; Ni 38-346; Co 0-180; Cu 26-226 ppm. Showings of protore mineralization (> 0.6% Mn) over 10,000 Km^2.

TABLE A-15 (continued)

Type or Name of Occurrence	Mn	SiO_2	P	Fe	Mining Character	Persistence Character	Remarks
Uzbek SSR– W. part of Zarafshan Khrebet Takhta-Karacha Deposit Rhodochrosite and rhodochrosite-manganocalcite ore:	14-16	Al_2O_3	<0.1	FeO 2-4	Overburden up to .2-.7500 m.	2 Mn-bearing carbonate layers w/variable thickness.	CaO 16-20%; MgO 1.3%; CO_2 22-28: org. C up to 1.4; insolubles 28-40%. Primary Mn and Fe-Mn ores are rhodocrosite, Ca & Fe rhodochrosite, Mn calcite, siderite. Secondary minerals consist of pyrite, marcosite, chalcopyrite. Reserves not reported.
Similar Deposits: Dautasch Kzyl-Bairak Ziaetdinsk							
SIBERIA							
Krasnoyarsk Kray Durnovsk Deposit braunite ores	6.5-26.5	15.5-48.6	.01-.11	2.2-13.3	9 braunite bearing lenses that are discontinuous but sometimes up to 180-200 m long with an average thickness of 4 m. underground.	The ore consists of separate layers and lenses interbedded with quartzite and porphyry rocks. Ore horizon thickness is 40-50 m, trending SE to NW for 300 m and dipping 45-50°.	2 types of Mn ores: (1) primary braunite ores (high SiO_2): (2) secondary psilomelane ores. S .09-.17; Zn 0.1-0.3% Reserves 600,000 MT of braunite at 20% or 850,000 MT at 9-10% Mn.
S. Krasnoyarsk Territory 85 shows altogether Arga, 15 showings incl. Mazul'skii Deposit Seiba (Eastern Sayan) Tom' Verkhtashtyp Gp. (Kuznetsk Ala-Tau)							"No economic interest." Genetically; sedimentation weathering and hydrothermal. Siliceous/carbonate below groundwater.
Mazul'skii Deposit	18.2-19 6.57 Protore		0.4	greater than Mn 13-18 (avg.) 14.4		Depends on degree of replacement.	Rhodochrosite, neotocite, mazulite, apatite, barite, sulphides, zeolites, siderite. 20 bodies in aggregate have 6.5 mill. MT. Worked between 1932-1955 "not exploited since 1956 be-

							cause of low grade and no beneficiation method". No use in near future. Can make ferro and silico from concentrates.
Gar'skoe Deposit, 4-5 km SW of Mazul'skii	av. 23				50 m long and up to 20 m thick friable	Splits and wedges	40,000 tons
Arga West Deposit						Discontinuous over 10 km., small bodies, irregular.	Reserves not calculated. 2 zones of mineralization.
Yakovlevskoe Dep. (25 km SW Achinsk)	av. 9.3 better 18.5			12.3	2.25 m. thick av. 12 m 300-500 m long	4 lenticular beds—irregular impregnations	Mn oxide and hydroxide in clay and soil. Reserves 17,000 MT!! Difficult to conc.
Seiba Deposits, upper Sisim R. valley, near Abakan-Taishet RR (several areas)	9.3 av. in weathered crust			7.0			Secondary Mn usually in redeposited weathering crust of siliceous Rx. and shales. Pyrol. limonite, psilomelane. 110,000 MT!! "Difficult to conc. high-P Fe-Mn ores"
Izyrtak, and	24.5	37.2	.4	9.1	16 bodies over 100 m x 20 m. 10-12 m. thick max. Dip to 25°.	"Mineralization disappears quickly with depth"	
Karaul'naya Gorka	21-39.7		.31-1.18	2.6-31.4	Dips 45-50°. 5-7 m thick; sheet-like; 200 m. strike.	Oxide to 80 m deep.	Friable earthy Mn and Fe oxides, clay, siliceous Rx fragments, marschalite. 8,600 MT!!
Tom' Verkhtashtype Gp. (20 showings low-grade) Bagzasskoe Area, upper Terensu River	3.5 Mn (15 where oxidized)		0.15-0.28	4-6	Horizon extends 2.5 km. 4.5-20 m thick	Oxidation only to 3.5 m.	Mn-Carb. silicate horizon, lower-Cambrian Protore is fine, grayish Mn-sed. garnet and pyroxene. Only 18-22% Mn carbonate. 16-20 CaO; 30,000,000 T protore "no interest, too low Mn and silicates in Bagzasskoe."
Ineiskoe	av. 3 Rare 8-10				4.5 km zone 150-180 m zone thickness	"No oxidation zone can be traced"	200 million tons—"their very low grade precludes economic exploitation"

TABLE A-15 (continued)

Type or Name of Occurrence	Mn	SiO_2	P	Fe	Mining Character	Persistence Character	Remarks
Tamalyk Phosphorite Deposit (10 km SW Bagzaskoe)	0.5-2.5 80-20 where leached (Vernadite)				1-2 m. or up to 10 m. thick	lenses in Mn-ls.	"Reserves were not evaluated"
Mt. Bol'shaya Kul'-Taiga	1-2					oxide showing in weathered zone	Carbonate-silicate "also of no economic importance"
Yenisei Ridge, over Ishimbai hematite deposit	3-5					"Insignificant primary sed. concentrations"	Mn-ls. is source of weathered crust.
Dzhot Mn Showing	14-28.5 oxide 1-14 protore				Dips 60°-80°	Orebodies formed close to source rocks.	Friable, earthy psilomelane. Protore Mn-ls. and altered schist. Mn source diorite eluvium.
USINSK DEPOSIT Usa River, Kemerov District Kuznetsk Atlatau Range	30% or more (Psilomelane-Pyrolusite oxide ore) to 30% more (Rhodochristic ore) av. 19.5 24.30 (Rhodochrositic-manganocalcitic ore) 20-24 (Rhodochrositic-ore) av. 19.1 manganocalcitic ore)		.2-.5		Oxide ore mainly near-surface to 50 m depth & 10 m. thick. Entire thickness of "ore" & waste bands–140 m dipping 70°-90°. 3 lens-shaped deposits over 4.6 km.	Deposits confined by sea-bottom depressions. Oxide weathering only to 50 m. fingers out to Mn-ls. Mn shale & Mn calcareous sh. 1%-10% Mn.	Concentrates suitable for Si-Mn and Fe-Mn. Oxide ore a "significant 6%" of "reserve". Enriched from Caledonian to end Paleozoic. In Lower Cambrian shales some hypergene oxidation to 125 m (in Azhigolsk & "Left-bank" (Levoberezhnaya). "Principal commercial reserve represented by the carbonate ores." "Oxidized weathered ore also has well known interest for exploitation." Rhodochrosite, pyrolusite, mangano-stilpnomelane, vernadite. Reserves–27,000,000 MT cont. Mn. Up to 30% of Mn in places occurs in silicates. "Hi-grade economic ores were found in Rt. Bank and Left Bank deposits. S=1.1-0.85 in primary carb. Al_2O_3 1.5-2.0; CaO 1-3 .1-.75 in oxide; Al_2O_3 = Tr. -13% (variable) CaO = 2-14.
	10-20 (manganocalcitic ore)	13-30			Prophyrite dykes every 20-30 m.		
	5-10 (Manganiferous ls)						
	27 weathered crust av.						
	Additional Chemistry: TiO_2 0.11; BaO .14-.3 in Carb.; 2.2 in oxide; LOI oxide 6.5-16.7.						
IRKUTSK OBLAST SAYAN MARGINAL TROUGH							Carbonate-terrigenous Rx. Upper Proterozoic littoral mar-

Tulun, Lower Udinsk and Taishet Oblasts 40-100 km to rail								ine; slightly metmorphosed. Primary oxide: braunite; hausmannite. Secondary oxide from carbonate: psilomelane and pyrolusite.
Uvat Group 40-50 km from Lower Udinsk	well oxidized deeper	 5-7	45-50	0.1-0.4	2-3 35-40	Dip 5-7° SW. Lenticular and nest-like;	Grade into eluvial seds. Thickness "varie	Prospected 1961/62. Elev. 1200
Uvat Group 40-50 km from Lower Udinsk Nikolaevskoe Dep.	well oxidized deeper crude	 5-7 22.8	45-50 45.5	0.1-0.4 0.3	2-3 35-40 4.9	Dip 5-7° SW. Lenticular and nest-like; length "several m to 100 m"; thickness: 0.5-3.5 m; rarely 10 m-15 m. Traced 400-500 m downdip. Ore lenses in groups underground.	Grade into eluvial seds. Thickness "variedly over short distances". Powdery in depth. Marked textural variations. Mn decreases with depth to only slightly mineralized rock.	Prospected 1961/62. Elev. 1200 m. max; Co 0.02-0.15%, LOI 8: Al_2O_3 2.8; CaO and MgO 0.55%; BaO 2.1%; 6-10 mm fraction = 19.7% of total conc. @ 50.7% Mn; 0.2-50 mm fraction = 47.5% of total conc. @ 43% Mn. With gravity and magn. can extract 43.7% of 6-50 and 89% of 0.2-50. S = 0.0045%; Cr_2O_3 0.014%. High Phos ore.
"Reserve Grade"		17		.09	2-4		"Economic concentrations of Mn occur irregularly" and are disturbed by relics of barren, partly oxidized ores & by low-grade ore zones. Composition extremely diverse. "Complex form and extremely heterogeneous."	Secondary oxide ores. Reserves based on 12 boreholes and 24 prospect holes and trenches = 6.8 mill. MT. Interlayered dol. has up to 15% Mn.
Kettskoe		12						
Kamenskoe		32			"Fe-Mn ore"			
Krasnoe		20.3			28.8			10 mill MT total Mn and Fe-Mn ores
"Areas between Deposits"		–						3.5 mill MT = 50,000,000 tons
Rudnoe Mn-Iron Ore		"Mn–Fe ore"	high		31			2.2 mill MT Mn ore is at base of weathered crust 17 mill MT 20-30 m. thick psilo- 25 mill MT melane and vernadite, hollandite, some pyrol. May be useful for chem. grade.
Arshan Showing–Primary		43-45		.002-.026	1.56-5.92	Possibly open cast. 0.15-0.9 m. thick 130 m long lense	Small, sheet-like Fe ores replaced down-dip by Mn ores.	Primary oxide. Cryptomelane braunite-hausmannite in pebble cg. "Reserves negligible". Ferruginous carbonate, quartz, calcite, Considerable alkali. No economic carbonate deposits detected in area. Interlayers of carbonate have 1-3% Mn.

TABLE A-15 (continued)

Type or Name of Occurrence	Mn	SiO_2	P	Fe	Mining Character	Persistence Character	Remarks
TRANSBAIKALIA AND BAIKAL							
N.E. of Barguzin, "ore showings" Ukat, Taloy, etc.	6-6.14		.06-.11	6-7	Best ore-bearing horizons 20-70 m; extensions to 250 m. along strike. Foliated micro spherulitic.	Mn bearing horizons divided by barren, sandy, silty, micaceous and carbonate rocks.	Lower-Cambr. greywackes and arkosic, sandy, silty, slatey shales, more or less carbonatized. N.E. end of Angarsk Chain and particularly associated with the longitudinal intermontane zone graben-depression; developed in the central part of the Baikal-Vitim uplift (early Cambrian). Some rhodochrosite and manganocalcite ore horizons. "Reserves": 20,000,000 MT.
Iliktin, Western Transbaikalia oxide	54-60	–	–	–	Not enough volume to be mineable. Lenses and nests to several meters; thickness to tens of cms. ying conformably.	No persistence.	Pyrolusite and psilomelane formed by weathering of Mn-bearing quartz-sandy-micaceous carbonates.
FAR EAST SIBERIA (KHABAROVSK) Lesser Khingan Group					Ore-bearing block 30-35 m thick, folded silicate rocks, finely laminated. Silico-Mn at bottom, Fe-silico at top. Ore zone underlies bed of dolom. breccia 1-2, up to 30 m. Mn bearing layer traced several hundred m. 8-9 m. thick in W, wedging to half in E.	At depth of 200-400 m. Transition observed from oxidized Mn-ore to oxide-carb. & carb.	Iron-silicate (jaspilite) genetic-type–Upper Proterozoic; S. part of Khingon-Burein uplift; strongly deformed tectonic zone. Ore-bearing suite 300-400 m. thick. Braunite/hausmannite, - primary oxide. Rhodochrosite, oligonite –primary carb. Rhodonite, bustamite, tephroite, spessartite, piedmontite near granitoid massif. Reserves: 10 mill. tons.
Near Amur R., Kimkan Station S. Khingan & Bidzhansk							
best primary oxide	35%						
siliceous ore	21						
N. Kazakh S.S.R. Zhaksy Deposit 3 km N. Zhaksy Station, Tselinograd Oblast (44 Mn showings/deposits in area over 180 km.)	av. 24.7 oxide 30.0 range 15-46	34.75	.05 0.62	6.21 4.05	Thickness varies laterally and vertically–5 cm-1 m. Strike 1.5 km. Dip 60° SE-90°. Entire deposit stretches over 8 km.	Sheet-like, lenticular, numerous thin (20-80 cm) totaling 10 m. Wedging out is gradual. Prim. oxide to 100-120 m. depth. Some holes	Tassbinsk Fm. volcano-sed. Mn in red, argillaceous shales; braunite interlayers; shales have 1.7-5.6% Mn, 5.8% Fe; oxide ore has 4.45 Al_2O_3, 2.05 CaO; 1.13 MgO, 0.006 S. About 0.5 km^2

						showed oxide to 210-230 m.	rubble ore 3 m. rarely to 7 m.–say 4 mill. T(?) Psilomelane, pyrolusite, vernadite and braunite; Genesis: sedim. and metam. and hydrothermal. Potential: ½ m. x 150 m. x 4,000 m. x 3 = 1,000,000 MT (?RLL'E)
Sagan-Zaba Lake Baikal, W. Shore					Dip 75-80°N. Mn-bearing massive crystallized ls, extends 700 m. from shore. Alternating bands with Mn and barren; several cm. to 1-2 m. thick. N. mineralized bed has 70 m strike. In W. gradually wedged out. Whole min. zone 15-18 m. Central ore layer: 380 m. strike and then wedges out. Thickness 4-17 m. S. Layer: 325 m. strike. Thickness: 10-30 m.	Variable Mn content in beds and layers (0.72%-22.52%) connected with uneven distribution in them of carbonate, calcite and Mn.	Reserves: 1 mill. T at about 6% Mn. "Often can be used as basic flux in smelgtin of various sorts of steel and a burden substitute in pig smelting of Fe-ores." Garnet, pyrox. amphib; and primary carbonate. W. shore of Lake Baikal, genetically related to marine geosyncline, Archean carbonate facies. Contemporaneous with band of metam. ls. of Lake series related to Ol'khon Island series of Upper Archean.
Mn-Limestones	av. 3.93-6.67	7.5-8.1	.09-.11	1.47-3.0			
Mn-Weathered caps	40-44						
Mn-silicate mineral layers	to 10	high					
N. Zone	6.67						
Cent. Zone	6.58						
S. Zone	3.93						
Western Pri-Baikal Iliktinsk Deposit pyrolusite and psilomelane nests	54-60%					Orebodies in the form of lenses and nests a few meters long and few *cm* thick.	Obviously no tonnage
Oldakitsk Deposit Rhodochrosite-manganocalcite ores	6.6-14	–	.06-.11	6-7		A number of ore horizons with the largest 20-70 m thick and 250 m. long but separated by barren beds.	Reserves estimated at 20 million tons.

TABLE A-15 (continued)

Type or Name of Occurrence	Mn	SiO$_2$	P	Fe	Mining Character	Persistence Character	Remarks
N. CAUCASUS Labinsk (Laba) Deposit In the area of stations Pereprausk, Gubsk, Hamketin, and New Freedom (Nova Svoboda)					Ore horiz. thickness 5 m. to 12 m.; extension to 250 m. Thickness determined by nearness to shore, in centre reaches 20 m. and abruptly increases on side of relatively deep, marine parts.	Lensy. Ore lenses, alternate with sandy, silty micaceous seds.	Manganiferous deposits extend in form of stretched bands over 25 km. between left tributaries of Laba, rivers Hadz and Fars. Represent sedimentation of deltaic facies; clastic, quartz-bearing calcitic rhodochrosite ore; ferrous-carbonate ore; oxide ore. Other Chemistry: Corg. .28-0.50, V 27-61 ppm, Gr 14-48; Ni 51-271, Co 9-30, Cu 16-30. Upper Pliocene quartz-glauconite sandy-clay. Reserves: about 30,000,000 MT @ 7.2-12.7% Mn.
carb. ore		24.95	.020	2.75			
Fe carb. ore		8.81	.081				
oxide ore		25.16	.035				
PRIOKHOTYA Udsk-Schantarsk Region Ir-Nimiisk Deposit braunite ores						Areal extent over 100 km. Mn ores localized in the siliceous type of rocks. Interbedded w/barren quartzites. Orebodies extend for hundreds of meters with 1-2 to 5-10 m. thick. Restricted to the contact zone.	Reserves estimated at 100 million MT for the total Udsk-Schantarsk Region. (Over 100 km areal extent)
massive-fine-grained		32-55	.04-.06	1.5-2.0			
lenticular		28-30					
carbonate ores (rhodochrosite and manganocalcite)		22-46					
USSR–General Weathered (enriched) deposits							"Only small deposits are known in USSR . . . obtained when other type of deposits are mined.
CONTACT METASOMATIC	Up to 15% Mn					Lenses: thickest 30 m w 1-2 km long.	
Manganocalcite (Ikat-Garginsk deposit)		20.2-24.5					"Insignificantly small reserves that do not have any practical economic considerations."
HYDROTHERMAL Taglio Kushvinsk Region						OT2 veins w/pyrolinite braunite, hausmannite, jacobsite, Rhodochrosite.	

References Used in Preparation of USSR Manganese Tables

Novokhatskii, I. P., Zhelezorudnye i Margantsevye Mestorozhdeniya Tsentral'nogo Kazakhstana i Perspectivy Dal'neishego Rosta Rudnoi Bazy Karagandinskogo Matalurgicheskogo Kombinata. (Iron and Manganese Deposits of Central Kazakhstan and Potential Development of Ore Reserves for the Karaganda Metallurgical Industry): Proizvoditel'nye Sily Tsentral'nogo Kazakhstana, No. 2, Alma-Ata, Izdatel'stvo AN Kazakhskoi SSR, 1959.

Sapozhnikov, D. G., Editor, Manganese Deposits of the Soviet Union, Izdatel'stvo Nauka, Moscow, 1967, 522 p. Translated from Russian, Jerusalem, 1970.

Smirnov, V. I., Editor, Rudnye Mestorozhdeniya USSR (Ore Deposits of USSR), Volume I, Izdatel'stvo "Nedra", Moscow 1974. Chapter on Manganese Deposits by Varentsov, I. M. and Rakhmanov, V. P., pp. 109-164.

Varentsov, I. M., Sedimentary Manganese Ores, Elsevier Publishing Company, Amsterdam, 1964, 119 p.

REFERENCES

Antropov, P. Ya., Rost Zhelezorudnoi i Margantsevoi bazy Chernoi Metallurgii SSSR (Development of the Iron and Manganese Ores and Iron and Steel Industry in the USSR), Suvremennye Problemy Metallurgii, ANUSSR Press, Moscow, USSR, pp. 24-35, 1958.

Avaliani, G.A., Marganets, Chapter on Ferrous Metallurgy (Chernye Metally) in Prirodnye Resursy Gruzii SSR (Natural Resources of the Georgian Republic). Vol. 1. Moscow, Moskva ANUSSR Press, pp. 37-77, 1958.

Baranova, H.M., Bass, Y. B., Bogdanovich, V.V., Vil'gos, E.F., Grazhdantsyev, I.I., Graznov, V.I., Gumorova, E.D., Kabrizon, V.M., Molyavko, G.I., Morokhovskaya, M.C., Nosovskiy, N.F., Romobanova, A.P., Sochnov, A.A., Usyenko, I.C., and Shevchenko, E.C., The Nikopol' Manganese Basin (Nikopol'skii Margantsyevorudnyi Bassein), Trudy Ukrainskogo Nauchno-Issledovatel'skogo Geologo Razvedochnogo Instituta, N. 4, Kiev, USSR, pp. 270-275, 1963.

Barskii, L.A., Machekhina, E.G., Mechurchlishvili, T..I., Grigalashvili, S.D., Shekriladze, N.S., and Samkharadze, M.B., Ispytaniya Flotomagnitoy separatsii margantsevykh shlamov na chiaturskoy flotatsionnoy fabrike (Tests of magnetic-flotation separation of manganese-bearing slimes in the Tchiatura flotation plant), Technology of Production and Beneficiation of the Mineral Resources of Georgia. Tbilisi, Metsniereba Press. pp. 76-84, 1977.

Betekhtin, A.G., and Dolidze, D.P., The Tchiatura Manganese Deposit, Resumenes de los Trabajos Presentados, XXth International Geological Congress, Mexico, pp. 309, 316, 1956.

Boyarskiy, V.A., Razvitiye Otkkytoy Bobychi Rud 1950-1970 GG. (Development of Open Pit Ore Production 1950-1970), Nauka Press, Moscow, USSR, 300 pp., 1975.

Ekonomicheskaya Gazeta, (Various issues, and No. 11, March 1977), 1979.

Gryaznov, V.I., Genesis of Manganese Ores of the Nikopol' Basin and Prediction of Marine Sedimentary Manganese Deposits Sapozhnikov, D.G., ed. Manganese Deposits of the Soviet Union, Izdatel'stvo, Translated from Russian, Jerusalem, 1970 Nauka Press, 522 pp., Moscow, USSR, 1967.

Kalandadze, B.A., Guro-Arazashvili, T.A., Ramishvili, P.P., Dzhaparidze, G.S., Kapanadze, D.G., and Abzianidze, Y.G., Improvement in the Technology of Secondary Recovery in the Tchiatura Manganese Deposits, Technology of Production and Beneficiation of the Mineral Resources of Georgia (Tekhnologiya Dobychi i Obogascheniya Poleznykh Iskopaemykh Gruzii). Tbilisi: Metsniereba Press, pp. 143-148, 1977.

Kikabidze, A.F., Optimizatsiya pokazateley izvlecheniya margantsevykh rud pri podzemoy dobyche (Optimization of the index of extraction of manganese ores by underground production), Technology of Production and Beneficiation of the Mineral Resources of Georgia, Tbilisi, Metsniereba Press, pp. 48-55, 1977.

Makharidze, A.I., On the Genesis of the Lower Oligocene Manganese Deposits of Georgia, Acta Mineralogica-Petrographica Szeged, XXI/1, Hungary, pp. 73-78, 1973.

Mamen, C., Back from Moscow, Canadian Mining Journal, Vol. 88, pp. 84-86, September 1967.

Ministry of Foreign Trade: USSR Foreign Trade--Statistical Review (Annual Publication), Ministers tvo Vneshnei Torgovli, Vneshnyaya CCCR, Statisticheskii sbornik, Mockba Statistika, Moscow, 1976 and other years.

Natarov, V.D., and Malakhov, N.L., Manganese-Bearing Ores of the Krivoi Rog Basin (Margantsevye Rudy v Krivorozhkon Basseine). Razvedka i Okhrana Nedr.3, pp. 4-6, 1961.

Sapozhnikov, D.G., ed., Manganese Deposits of the Soviet Union, Izdatel'stvo, 522 p., Nauka Moscow, USSR (Translated from Russian, Jerusalem, 1970), 1967.

Sereda, G.L., Lesnikov, S.V., and Yarovoi, I.I., Scientific-Technical Progress in the Open Pits of the Ordzhonikidze GOK (Nauchno-Tekhnicheskii Progress na Kar'erakh Ordzhonikidzevskogo GOKa), Gornyi Zhurnal, No. 1, pp. 18-21, 1973.

Shnyukov, E.F., About the Ingulets Manganese Deposit (Ob Inguletskom Margentsevom Mestorozhdenii), Geologiya Rudnykh Mestorozhdeniy 2, pp. 132-135, March-April 1961.

Varentsov, I.M., Sedimentary Manganese Ores, Elsevier Scientific Publishing Company, Amsterdam, Holland, 119 pp., 1964.

Yarovoy, I.I., Sereda, G.L., Gergel', M.G., Vidyaev, G.M., Poznyakov, V.V., Gorinskiy, M.M., and Chizhov, A.A., Technical Progess in Manganese Open Pits (Tekhnicheskii Progress na margantsyevykh kar'erakh). Nedra Press, Moscow, USSR, 93 pp., 1977.

Zereteli, D., Manganese Ore, with Special Reference to Georgian Ore, Dryden Press, J. Davy & Sons, Ltd., London, U. K., 136 pp., 1925.

A.7 YUGOSLAVIA

Yugoslavia, which imports about 75% of its manganese requirements, has had domestic production since 1870. Output has averaged about 8,000 tons of ore and concentrates annually, with the highest output of over 30,000 tons in 1918. In recent years annual production has fluctuated between 8,000 and 16,000 tons.

The grade of material produced has been in the range of 30 to 38% manganese with high silica and iron content, which indicates that it generally is not of metallurgical specification. In the early years of mining, some small, high-grade ore bodies were worked, but in recent years most ore produced has been low-grade milling ore.

Little detailed information about the total known resources is available, but according to the Mining Journal (November 14, 1975) there could be at least 30 million tons. Without much doubt, this resource is spread out over a great number of small to medium, low-grade deposits.

The great majority of manganese deposits are found in eugeosynclinal volcano-sedimentary series that evolved during different geologic periods and in different areas. Some are Paleozoic and a few are considered to be of Cretaceous-Paleogene age, but most were formed during Triassic and Jurassic times. Manganese appears to be omnipresent in these formations and occurs in many places in more concentrated form. The primary deposits, often associated with iron, occur as layers, lenses, and pockets, mainly in chert or jasper. Some ore occurs in shales or sandstones intercalated in the series, or in overlying limestones. The manganese, along with much silica and iron, was deposited as a chemical precipitate, more or less mixed with detrital sediments, apparently under shallow, near-shore sea conditions. Submarine volcanics are thought to be the source of the manganese, silica, iron, and certain accompanying minor metals.

As part of the geosynclinal series these volcanogene-sedimentary (exhalative) formations have been subjected to strong orogenic deformation and regional metamorphism. Later supergene alteration and enrichment, generally of rather limited importance, have resulted in the development of some small, high-grade deposits up to a few thousand tons each.

In addition to the volcanogene deposits, which are the most abundant type, there are a number of hydrothermal deposits where the manganese occurs as carbonate in association with lead, zinc, and silver mineralization. The grade usually runs 5 to 15% manganese in the primary ore, but may be 30% or more in the supergene oxidized zone.

A.7.1 Bosnia-Herzegovina

This republic contains over 250 occurrences of manganese, mostly associated with the Mesozoic volcanogene-sedimentary series. Most of them occur in the northern half of the republic in a large area north of Sarajevo, covering an area of about 600 km^2. The manganese occurs in one stratigraphic zone as layers, lenticles, and pods, from a fraction of a millimeter to about one meter thick. Most of it is in close association with chert, although some is found in argillaceous schists and limestone. In some places alternating layers of ore and barren rock form a mineralized zone up to 5 m thick, but the total thickness of the manganese layers may be only about 80 cm. Because of strong deformation, the beds have variable dips, often so steep that they can seldom be worked by open-pit. The principal manganese mineral is braunite, deposited as a primary mineral, accompanied by smaller amounts of different manganese oxides and hematite.

Most of the deposits are low-grade and highly siliceous. The individual ore bodies appear to be small, probably being measured at most in a few hundreds of meters. They have only locally been enriched by supergene weathering to cryptomelane and pyrolusite that may contain 30 to 35% manganese and 10 to 20% SiO_2.

The Cevljanovici deposit in this area appears to be one of the most important producers of manganese in Yugoslavia, having been worked since 1885. The most intensive exploitation took place during the period 1914 to 1918, when annual output was on the order of 20,000 to 30,000 m.t. During 1948 to 1956 the annual output varied between 3,200 and 4,000 m.t. and this may still be the level of the present production. Total output to the present can be estimated at almost 500,000 m.t. The layers and lenses of ore are between 0.3 and 2 m thick. The manganese is associated with much chert and locally with some barite, galena, and other sulfides. The washed and concentrated material was reported in 1960 to contain 33 to 35% Mn, 7 to 10% Fe, and 20% SiO_2.

In the northwestern extremity of Bosnia near Karlovac, numerous occurrences and deposits have been reported. In 1969 it was reported that several million tons of reserve still existed. At that time the facilities for producing concentrates included a new beneficiation plant with a capacity to handle some 30,000 m.t. of raw ore per year. Other occurrences of manganese are known in northern and eastern Bosnia. They are mainly small volcanogene-sedimentary deposits of little economic importance. The manganese is always associated with iron and several occurrences are indeed iron deposits with low manganese values.

Southwest of Sarajevo there is a 30 km belt that again contains many volcanogene-sedimentary deposits. The bedded ore bodies, which grade from essentially manganese-oxides to iron-oxides, are 100 to 500 m long and up to 14 m thick. They are similar to those in eastern Bosnia and apparently of little economic importance for manganese, most occurrences being mainly iron ore. A few occurrences of 40% manganese have been reported, for instance at Brzolin and Crnivrh, but the known tonnages appear to be quite restricted.

A.7.2 Macedonia

In the Republic of Macedonia, in the extreme southern part of Yugoslavia, there are a number of manganese occurrences that comprise the Cer deposit near Kicevo. Data available indicate that during 1948 to 1956 production fluctuated between 4,800 and 9,200 m.t., representing 51.6% and 69% of the total annual production of manganese ore in Yugoslavia. Thus, the Cer deposit was, at least during this period, the most important manganese mine in the country.

Manganese occurs at the contact between the quartzites and the overlying marble, which appears to be stratigraphically above the local volcanogene sediments. It forms interconnected lenses of varying dimensions that constitute an irregular ore body. The ore was mined in three main underground levels with grade reported as 35% Mn, 13% Fe, and 10% SiO_2. In 1960 the mine was considered as almost depleted.

Southwest of Kicevo there is a complex zone of several manganese deposits in the general area of the Bistra Mountains. Four typical deposits, none of which is known to be in operation at present, are shown in Table A-16.

TABLE A-16. MANGANESE DEPOSITS NEAR THE BISTRA MOUNTAINS (YUGOSLAVIA)

Name	Tonnage(m.t.)	Mn(%)	Fe(%)	SiO_2(%)
Uzinica	400,000	26.61	5.58	25.45
Karadere	3,000,000	22.30	5.38	21.29
Vrabjansko	1,300,000	21.09	5.24	21.24
Babinsrt	8,000,000	29.06	5.51	22.47
Wt. Avg.		26.5		

There are no data available on tests to upgrade this material for ferromanganese manufacture. For a number of years, the government enterprise, Jugometal, has contemplated a new ferromanganese facility in Kicevo using these or similar ores, but it is not known if the project has been developed. There are countless other manganese occurrences in Serbia, Montenegro, and Dalmatia, but data on hand indicate they are all small and very siliceous and ferruginous, similar to those described above.

It would appear that the 30 million m.t. resource referred to above is indeed an aggregate of quite a number of widespread deposits of varying manganese content throughout the entire country, the grade of which would remain below 30% manganese. For purposes of this report, Yugoslavia does not appear to have the potential for high-grade export ore of any significance. While there may be a small reserve of mineable, high-grade oxide ore, it probably totals no more than 1 to 2 million m.t. in separate, well-scattered deposits, and it would be destined for the local market. The 30 million m.t. resource of low-grade ore is classified as a subeconomic resource at 26.5% manganese in Table 3-8.

BIBLIOGRAPHY

Antula, J., Revue generale des gisements metalliferes en Serfie, USGS Library, Reston, Va., No. 430 (596) An8r, 1960.

Celebic, D., The Sedimentary Iron and Manganese Deposits in the Diabase-Chert Formation of N W Herzegovina, Geol. Glassnik 7, 1963.

Celebic, D., Geology of the Area Between Konjic and Prozor (Bosnia-Herzegovina) with Special Reference to Deposits of Iron and Manganese, Geol. Glassnik, Sarajevo, 1967.

Cissarr, A., Lagerstatten und Laberstatten Bildung in Yugoslavia, Serv. Geol. Geoph. Rep. Serbia 6, 1956.

Cissarr, A., Einfuhrung in die allgemeine und systematishe, Lagerstatten Iebre, 2nd ed., 1965.

Geological Society of France. Numerous articles on the Geology of the Dinarides in Yugoslavia. Bull. Soc. Geol. France, 7°Serie, Vol. XII, No. 6, 1970.

Jankovic, H., Economic Geology, Belgrade, 1960.

Jeremic, V.L., The Manganese Beds and Occurrences in Bosnia and Herzegovina, Prirod Musej, Glasnik A., 1959-1960.

Mulina, C., Manganese Deposit Novo Brdo and Estimation of Mineral Bearing Potential of the Unexplored Zone, Tehknicka (Belgrade) 29-12-T-13-Tig, 1974.

Simic, V.L., The Manganese Deposit of Popoksie Palje in Northwestern Bosnia, Geol. Glassnik, Geol. Instit. Sarajevo, Bull. No. 8, Sarajevo, Yugoslavia, 1963.

U.S. Bureau of Mines, Minerals Yearbooks, Washington, D.C., U.S. Government Printing Office, 1945-1972.

Vujanovic, V., Mineralogy, Geochemistry and Genesis of Manganese Deposits in the Bistra Mountains, Geol. Glassnik, Series A, N-14-21, 1961-1966.

Vujanovic, V., The Manganese Deposit of Cer (Kicevo) Prirodnjacki Musej, Geol. Glassnik, Series A-14-21, 1961-1966.

Vujanovic, V., Mineralogy, Geochemistry and Genesis of Sedimentary Manganese Deposits of Yugoslavia, 1963.

Vujanovic, V., Manganese Occurrences in the Area of the Montenegro Coast, Geol. Glassnik, Series A., No. 22-24, 1967-1970.

Vukasinovic, H., Principal Geotectonial and Metalogenetic Units of Yugoslavia, 1974.

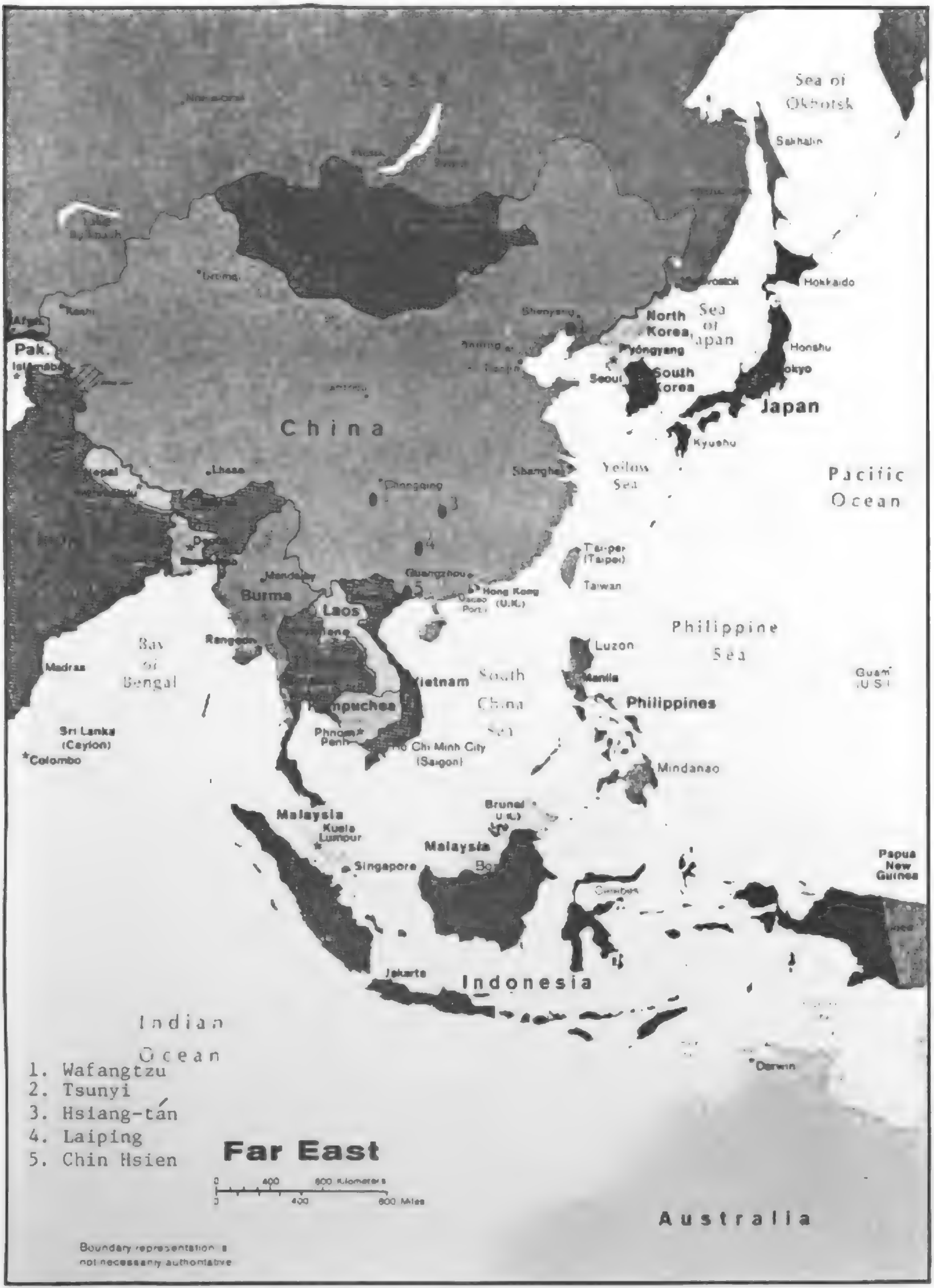


FIGURE A-9. Operating Mines in China

AFRICA

A.8 GABON

The manganese deposits at Moanda are situated in the extreme southeast corner of Gabon to the west-northwest of Franceville. Moanda is the world's largest single producer-exporter of manganese, and metallurgical- and battery-grade concentrates. Production is limited to one company, Cie. Miniere de l'Ogooue (COMILOG). The occurrence of manganese was first described in the region of Franceville in 1895, with further discoveries in 1934 and 1944 to 1945. Systematic exploration was started in 1951 and the Bangombe Plateau deposit was brought into production in 1962.

A.8.1 Production and Chemistry of the Deposits

Production was slowly built up until it exceeded 2 million m.t. of product in 1974. In 1978, COMILOG shipped a total of 1,694,416 m.t. of manganese salable product, of which 1,603,057 m.t. consisted of metallurgical grade concentrates at a grade of about 51% Mn and 91,359 m.t. of battery grade at a grade of 83 to 85% MnO_2. During 1977, a total of 1,859,000 m.t. was shipped.

The Moanda metallurgical product has an average grade of 51.52% Mn, 2.81% Fe, 2.01% SiO_2, 5.62% Al_2O_3, 0.114% P, and 0.14% CaO. The battery grade dioxide has an average grade of 83.64% MnO_2, 3.04% MnO (Mn total 54.85%), 1.84% Fe, 1.06% SiO_2, 4.67% Al_2O_3, and 0.08% P (Weiss, 1977).

The amount of product that can be shipped annually is restricted to 2.7 million m.t., the carrying capacity of the aerial ropeway-railway to Mbinda at the Congolese border, a distance of 74 km. At Mbinda, the manganese is transported via railroad to the port of Pointe Noire, 560 km away. It is expected that production will increase to 4 million m.t. per year once the proposed trans-Gabon railway from Santa Clara (25 km from Libreville) is completed.

The ore is mined by open-pit methods, using 600 to 900 m trenches, 20 m wide with backfill of the waste. The stripping ratio is 1 metric ton of waste to 1 metric ton of crude ore (W.A. Preston, British Steel Corporation, presentation to the committee, August 1979).

The ore beneficiation consists of crushing, screening, and drum-washing to produce two high-grade products, plus 6 minus 200 mm and plus 20 minus 125 mm. The fines less than 6 mm are largely wasted and some 10 million tons of this material are stored at Moanda. The overall recovery ratio is about 55 to 60%. The crude ore has a grade of about 44% manganese. Specially selected ores from the washing and screening plant are crushed to 1 mm and concentrated on a series of vibrating tables to a final product containing 83 to 85% MnO_2, the battery grade concentrate.

A.8.2 Ore Persistence Character

The manganese deposits are found in five plateaus in an area surrounding Moanda. Listed largest to smallest they are Bangombe, Okouma, Bafoula, Massengo and Yeye. The most important are the Okouma plateau, with a mineralized area of 13 km^2 and the Bangombe plateau, with a mineralized surface area of 19 km^2 that is currently being exploited.

The deposits are the result of supergene enrichment of Precambrian Francevillian sediments. The protore is believed to be manganese carbonate, i.e., rhodochrosite-bearing carbonaceous black shales that have grades of 10 to 20% manganese and are at depths of 23 to 32 m in two of the drill holes (Leclerc and Weber, 1976). The shale overlies an iron formation, particularly on the Okouma Plateau.

The ore zone is comprised of a thin (0.2 to 0.5 m) basal unit of massive manganese oxides and hydroxides with accessory secondary manganese carbonate (rhodochrosite). This is overlain by a 3 to 9 m unit of plaquettes of similar mineralogy that constitutes the major part of the ore zone. Plates of ore are found in an ochrous matrix containing small fragments of mineralization around which small pisolites occasionally have developed. Intercalated with the ore beds are argillaceous, siliceous, and ferruginous bands. The principal manganese minerals are pyrolusite, manganite, polianite, nsutite, psilomelane with ramsdellite, hausmannite, and crytomelane. The plaquette unit is overlain, after a thin transitional layer by 5 to 6 m of a loose pisolitic layer with abundant alumina and iron-rich manganiferous pisolites. This layer, which is not exploited, has a manganese content of 15%.

A.8.3 Reserves

The reserves and resources are dispersed over the five plateaus with the reserves having been developed for the Bangombe and Okouma plateaus. The reserve estimate is reported as 200 million m.t. of product at 50% manganese. Of this total, approximately 75 million m.t. of product equivalent are in the measured and indicated categories (W.A. Preston, presentation to the panel, 1979). The total product is equivalent to about 400 million m.t. of crude ore. The product reserve figure can be reduced by about 6 million m.t. to reflect the production since 1976. Further tonnage may be developed on the other three smaller plateaus.

A total of 359 drive pipe holes and 149 pits have been made in the area, according to Preston. The whole area is drilled on a 1,000 m grid that is quoted to give a confidence level of 75%. The drilling is further closed up to 250, then to 125, and finally to a 63 m grid at the preproduction stage.

A.8.4 Resources

The manganese carbonate-bearing shale protore may be a significant but submarginal hypothetical resource, provided it will not require excessive stripping and that the manganese can be recovered by beneficiation. Much exploration has taken place in the surrounding Moanda area, but no other deposits have been discovered.

REFERENCES

Leclerc, J. and Weber, F., Geology and Genesis of the Moanda Manganese Deposits Republic of Gabon, Paper presented at 25th International Geological Congress, Australia, 1976.

1978 Comilog Manganese Ore Exports at 1,694,416 m.t., Skillings Mining Review, 68/17, p. 17, April 18, 1979.

Tienken, A.T., Gabonese Manganese Sector Activity, Unclassified Document, Secretary of State, Washington, D.C. from American Embassy, Libreville, Gabon, April 24, 1979.

Weber, F., Genesis and Supergene Evolution of the Precambrian Sedimentary Manganese Deposits at Moanda (Gabon), Genesis of Precambrian Iron and Manganese Deposits, Proceedings of the Kiev Symposium, 20-25 August, 1970, pp. 307-322, UNESCO, Paris, 1973.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Book Ltd. Garden City Press, Ltd., Hertfordshire, U. K., 1977.

A.9 GHANA

Although low-grade manganiferous metamorphosed sediments are widely distributed throughout the Precambrian formations of Ghana, the primary source of high-grade manganese has been the Nsuta deposit in the Tarkwa District. The manganese-bearing sediments occupy an extensive zone in Upper Birrimian greenstone belts and often occur as surficial caps of no economic importance. Production of high-grade oxide ore from the Nsuta deposit since 1916 has been over 25 million tons, but since the middle 1960's, production has gradually declined.

About half of the surface of Ghana is made up of rocks of the Precambrian Birrimian system that dates back about 2 billion years. This system is divided into a lower series of metamorphosed, mainly pelitic flysch-type sediments and a more restricted upper series of geosynclinal greenstones that are largely metamorphosed basic lavas and pyroclastics with intercalated bands of phyllite and graywacke.

The Upper Birrimian greenstones are distributed throughout the Precambrian as several, generally northeast trending, discontinuous belts. Syngenetic, more or less manganiferous sediments, folded and metamorphosed with the surrounding rocks, occur in the upper part of the greenstone series. These rocks are largely manganiferous phyllites and gondites. The manganiferous formations are present in many areas of the country, and supergene weathering and enrichment have given rise to numerous occurrences of manganese oxides. In the majority of cases, these manganese occurrences appear to be of no economic interest.

A.9.1 The Nsuta Deposit

The Nsuta manganese mine is situated in the Tarkwa District in southern Ghana, about 60 km by the connecting railroad to the seaport of Takoradi.

A.9.1.1 Geology

Morphologically, the Upper Birrimian sequence is delineated by isolated low hills and ridges partly formed by the erosion-resistant manganiferous formations. During Tertiary time, the area was part of a lateritic peneplain that was subsequently uplifted and dissected. The higher hills and ridges are still capped by laterite.

The Upper Birrimian greenstones, folded along north-northeast striking areas, comprise a sequence about 450 m thick, consisting of sericite-graphitic phyllites, tuffs, and graywackes, and an upper manganiferous zone, 120 m thick, composed of manganiferous phyllites and gondites. Some 300 m below this zone there is a second, narrow, manganiferous phyllite layer. These formations extend in a northerly direction a distance of more than 30 km with 60 to 90° dips. The manganiferous phyllites contain some 0.5 to 2% manganese, but some local values up to 15% have been reported. The gondites appear to contain from 15 to 25% manganese.

The known workable deposits are in the upper manganiferous horizon. They are confined to the Nsuta area where the main ore bodies are outcropped on 5 hills and aligned in 2 parallel north-northeast zones over a length of some 3 km, presumably representing the 2 limbs of an isoclinal, eastward-dipping fold. The formations have been subjected to strong cross faulting, which has displaced the ore bodies. The ore bodies are conformable, tabular lenses up to 300 m long, 25 m wide, and over 130 m deep.

A typical section through the ore body shows a surface layer about 10 m thick, consisting of detrital ore (40% manganese) and overlying the eastward-dipping ore zones and the surrounding weathered phyllites that contain irregular blocks and patches of manganese ore. The upper part of the main ore body is hard, lateritic ore (50 to 55% manganese) almost devoid of quartz. At depth, the ore gradually changes to a soft, porous, black ore that contains thin seams of clay and is cut by numerous veinlets of quartz. The three types of ore include: 1) Ore replacing pre-existing rocks and containing relicts of muscovite and quartz; 2) cavity fillings and veinlets; and 3) residual ore.

The ore minerals are essentially pyrolusite, cryptomelane, and battery grade MnO_2 (nsutite) with some manganite, lithiophorite, and goethite. Spessartite occurs in deeper levels in the gondite and manganiferous phyllite.

For a long time it was assumed that the ore would grade into unaltered gondites and manganiferous phyllites at depth. The mineralization was believed to be entirely related to Tertiary-Quaternary supergene alterations of the source rocks. However, deep exploration in the late 1950's showed that at depth, the oxide ore bodies grade into manganese-bearing carbonate rock. Accordingly, the oxide bodies appear to be essentially supergene enrichments of the syngenetic carbonates, with only a small part of the oxides deriving from the alteration of the gondites and phyllites. Conceivably, some of the oxides also represent primary ore. Thus, the Nsuta deposit appears to be similar to those in Brazil and Zaire. In some places the manganese carbonate ore apparently is cut off at depth by the roof of a younger, granitic porphyry intrusion.

A.9.1.2 Production History

The deposit was discovered in 1914 and limited production began in 1916. The mine was acquired by African Manganese Co., a subsidiary of Union Carbide, in 1923 and was mined continuously until the property was nationalized in 1975. Mining is presently being conducted by the Ghana National Manganese Corporation. With the gradual depletion of the oxide reserves during the last five years, the carbonate ore is being mined to supplement the declining oxide production.

The total production of ore since the start of operations has been estimated to be over 25 m.t., with an average annual output of about 500,000 m.t. For several decades, Nsuta was the world's principal source of battery-grade ore (54.8% manganese) and producer of important quantities of metallurgical ore (over 48% manganese). Since the early 1950's, however, only a small part of the production has been battery-grade. The peak year of production was 1951, when over 900,000 m.t. of high-grade ore was mined.

The Nsuta mine is a mechanized, relatively modern open-pit operation, with a 3,000 tpd capacity. Hand picking and a treatment and sintering plant were employed to obtain a high-grade ore product. This plant, designed to process the oxide ore, produced a product that contained about 50% Mn, 2.98 to 3.79% Fe, 7.4 to 8.3% SiO_2, 3.5% Al_2O_3, and 0.10 to 0.12% P.

In 1978, Nsuta produced 321,000 m.t. of manganese ore, of which 115,000 m.t. were carbonate. The ore reserve situation is being appraised as the result of the decision to proceed with the construction of an $18 million roasting/nodulization plant. The Fuller Company was awarded a contract to construct the plant designed to process 1,000 to 1,100 tpd of carbonate ore. The plant is scheduled to come on line in 1981.

A.9.1.3 Export Market

With the near depletion of the Nsuta oxide ore, the future of this mine depends on the marketability of the carbonate ore. Manganese exports in 1976 were approximately 350,000 m.t., of which roughly 150,000 m.t. were carbonate ore and 200,000 m.t. were oxide ore, mostly metallurgical grade. All battery-ore exports were destined for the United Kingdom. The carbonate ore was sent to synthetic dioxide plants in Japan and Ireland and to electric furnace ferromanganese plants in Norway, Portugal, and other markets where it was used to make up about 15% of the furnace charge.

A.9.1.4 Reserves

Exact reserve figures of the remaining oxide ore are not available, but it appears that the ore is very close to being depleted. Reserves of carbonate ore, based on limited drilling, amount to about 20 million m.t. of 30% manganese. Additional carbonate resources undoubtedly exist, but the order of magnitude is unknown.

REFERENCES

DeHuff, G.L. and Jones, T.S., Manganese, Mineral Commodity Profile, July 1979, U.S. Bureau of Mines, U.S. Department of the Interior, Publications Distribution Branch, Pittsburgh, Pennsylvania, 1979.

Engineering and Mining Journal, 1980 Survey of Mine and Plant Expansion, 181, 86, January 1980.

Michel, H., Manganese Ore in Ghana, Bethlehem Steel Corporation, Geology Department, Internal Report, November 1974.

U.S. Bureau of Mines, Minerals Yearbook, Vol. I - Metals, Minerals, and Fuels, U. S. Government Printing Office, Washington, D. C., 1976.

World Mining, Worldwide Mining Developments, Country Production and New Projects in 1978, Vol. 32/8, p. 169, July 25, 1979.

A.10 MOROCCO

(See Figure A-6)

There are two principal manganese districts in Morocco: one in the eastern part of the country at Bou-Arfa near the Algerian border and one on the southeastern flank of the Atlas Mountains near Ouarzazate. There has been no reported production from the Bou-Arfa district for many years.

The sole manganese mining operation in Morocco now is at Imini, located about 40 km northwest of Ouarzazate, between the High Atlas and the Anti Atlas Mountains, and about 160 km by highway south of Marrakesh. Casablanca lies toward the north at a distance of 400 km.

The annual average production from Morocco ranged from 300,000 to 570,000 m.t. during the years 1950 to 1966. Currently at Imini, an annual average of 100,000 m.t. of processed ores are shipped from a mine production at 120,000 m.t. (Weiss, 1977). The peak production of nearly 175,000 m.t. was shipped in 1974. There are a wide variety of shipped products, ranging in grade from 74 to 94% MnO_2, and practically all of the production is for nonmetallurgical and nonbattery uses, i.e., in ceramics and chemicals. The fines content of the ore, plus its lead and copper content, limits its use metallurgically. The products are hauled by truck across the High Atlas Mountains to Marrakesh, where they are loaded into rail cars for transport to either Casablanca (240 km) or Safi (230 km) for export.

At Imini, the manganese occurs in 2 to 3 beds associated with Cenomanian dolomites. The main manganese horizon is made up of ellipsoidal beds extending over a distance of 19 km and having workable widths of 150 to 400 m. The overall shape of the ore body is tabular, with an average thickness of 1 m. Overall it dips 5° toward the east. Mining is by underground room and pillar methods, with pillar drawing. Depths below the surface range down to 120 m. The ore is friable and fine grained and requires little drilling and blasting. The ore is composed chiefly of pyrolusite and psilomelane, with an overall grade of 46% Mn and less than 1.0% Fe. The ore contains objectionable amounts of lead and copper for metallurgical use. Ore grading begins at the mine face, where the ore is segregated into different types that are then kept separated during subsequent processing. About 10 different grades are handled separately.

The reserves at Imini are 1.8 million m.t. of 46% Mn. Additionally, there are 500,000 m.t. indicated and 1.3 million m.t. inferred. The ores are also reported to contain 0.07% P, 0.8% Pb, 0.2% Cu, and from 0.2 to 0.8% K_2O. Other occurrences of manganese ores have been identified at a number of other localities near Imini and along the eastern flank of the Atlas Mountains. Manganese deposits located in the upper Sousse Valley near Tasdremt and Idikel are associated with stratigraphic horizons similar to Imini. These deposits produced about 100,000 m.t. from 1951 to 1959. A number of vein type or fracture-filled deposits with low tonnage potential are reported in upper Precambrian rocks around Ourzazate. No development of these deposits is known.

REFERENCES

Bouladon, J. and Jouravsky, G., Les Gites de Manganese du Maroc (Suivi d'une Description des Gisements du Precambrien III), Symposium on Manganese, Vol. II, 20th International Geological Congress, Mexico, 1956.

Mining Annual Reviews, 1976-78, Mining Journal, U.S. Bureau of Mines, Washington, D. C., 1976-78.

Minerals Yearbooks, U. S. Bureau of Mines, U.S. Government Printing Office, Washington, D. C., 1974, 1975.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books Ltd., Garden City Press Ltd., Hertfordshire, U. K., 1977.

A.11 REPUBLIC OF SOUTH AFRICA

The principal manganese producing area of South Africa is located in the Northern Cape Province between latitudes 27 to 29° south and roughly along 23° east longitude. It consists of two districts, the Postmasburg and the Kuruman (Kalahari). The Postmasburg District, which is the southernmost of the two, extends about 65 km from the town of Postmasburg to Sishen, while the 41 km long Kuruman District starts about 105 km north of Postmasburg.

The South African manganese production is dominated by two companies: S.A. Manganese Ltd. (Samancor) and The Associated Manganese Mines of South Africa Ltd. (Ammosal). Samancor operates the underground Wessels mine and the open-pit Mamatwan mine in the Kuruman District and the open-pit Lohathla mine in the Postmasburg District. Ammosal is mining from three underground mines in the Kuruman, i.e., Black Rock, Gloria, and N'Chwaning, and three open-pit mines in the Postmasburg. The Kuruman District provides in excess of 75% of the total production.

National Manganese Mines (Pty) Ltd. has a small production from the Langdon open-pit mine. Anglo American Corp. brought their underground Middelplaats mine into production in mid-1979. Both of these mines are in the Kuruman District.

The manganese deposits in the Northern Cape Province were discovered in 1922 and ferruginous manganese was first mined at Lohathla in 1926. In 1955 Ammosal started mining at Black Rock and Samancor at Hotazel in 1959 in the Kuruman District. Production of metallurgical ores was slowly built up as other mines came into production (Devon, Smartt, Adams, etc.) and exceeded 1 million m.t. in 1960. The metallurgical beneficiated ore produced for the years 1972 to 1978 is shown in Table A-17.

TABLE A-17. SOUTH AFRICAN METALLURGICAL MANGANESE PRODUCTION (m.t.)

YEAR	MANGANESE ORE TYPE IN GRADE				
	30-40% Mn	40-45% Mn	45-48% Mn	48+% Mn	Total
1972	2,142,653	174,607	116,509	743,467	3,177,236
1973	2,629,137	246,443	278,193	934,983	4,088,756
1974	3,026,152	264,464	218,185	1,138,323	4,647,124
1975	3,872,052	232,947	1,379,230	199,274	5,683,503
1976	3,358,080	209,348	1,517,353	269,608	5,354,387
1977	2,838,758	576,894	1,197,784	262,995	4,876,401
1978	2,356,654	429,995	1,131,267	262,079	4,179,995

Source: Republic of South Africa, 1972-1978

During the same period, a total of 771,437 m.t. of chemical grade ore was produced primarily at grades of less than 35% to over 85% MnO_2, as well as 758,307 m.t. of manganiferous ore at 15 to 30% Mn and 20 to 35% Fe.

At present, manganese ore exports from the Kalahari Region are transported by rail via Postmasburg and Kimberly to Port Elizabeth some 950 km distant. A new line has been constructed from Sishen to Saldanha Bay, north of Cape Town, a distance of about 800 km. The manganese ore is hard and tough and stands up very well during transport with a minimum generation of fines.

A.11.1 Kuruman (Kalahari) District

The ore occurs as two major types: the high-grade, mainly braunite-hausmannite Wessels type, and the self-fluxing carbonate, mainly braunite Mamatwan-Middelplaats type. Typical analyses of the types are shown in Table A-18. Associated Manganese Mines produces the grades of lump ore listed in Table A-19.

A.11.1.1 Wessels

All the mines in the Kuruman District are underground except the Mamatwan and the Langdon. Semancor's Wessels mine in the northwest part of the district is mined by room and pillar method, with access provided by a vertical shaft and inclined ramp. A second incline with a conveyor belt is planned for future expansion. Two separate zones of manganese are present. In the shaft area, the upper one is at a depth of about 370 m and the lower at about 385 m. A third zone, the middle layer, occurs but is not being mined due to erratic mineralization and thickness.

The two ore bodies are of variable thickness, but are mainly between 3 and 5 meters and mined using modified load-haul-dump (LHD) loaders, rear-dump trucks, and single-boom drills. It was initially planned to use 3 m square pillars with 6 m wide rooms. However, because of spalling, the pillar size was increased to 8 m with roadways and crosscuts 8 m wide giving a mining recovery before losses of about 75%. A 90% extraction recovery is envisaged, employing a retreat system whereby pillars are robbed (W. A. Preston, British Steel Corporation, presentation to the Committee, August 1979).

In places the ore bodies are horizontal and easy to work, whereas elsewhere they are structurally complex with rolls, folds, and minor faulting. A fault with a 35 m vertical displacement occurs immediately to the west of the shaft; parts of the ore body are ferruginized. The production capacity is rated at 1.5 million m.t. per year of salable product at +47% manganese, but is currently producing at about 1 million m.t. per year.

TABLE A-18. TYPICAL ANALYSES OF KURUMAN DISTRICT ORES (%)

	Wessels	Mamatwan	Middelplaats		
	Lumpy	Lumpy	M1 Lump	M2 Lump + Fines	Ferruginous Lumpy
Mn	+47	+38	38-40	34-36	33
Fe	12-14	4-6	4.0	4.5	5.0
SiO_2	3-5	4-6	5.0	5.0	5.0
CaO	4-6	9-13	14.0	16.0	18.0
MgO	0.4	3.5	-	2.6	3.5
Al_2O_3	0.5	0.5	0.5	0.5	0.5
P	0.05	0.05	0.03	0.03	0.03
S	0.12	0.03	0.04	0.05	0.05

Normal Sizing-Lump -63 mm +10 mm — -75 mm + 6 mm
-Fines -10 mm — -6 mm + 2 mm

SOURCES: Weiss, 1977; Middelplaats Manganese Ltd., 1978; S. A. Manganese Amcor Ltd., 1978

TABLE A-19. TYPICAL ANALYSES OF LUMP ORE FROM ASSOCIATED MANGANESE MINES (%)

	Wessels	Mamatwan	Middelplaats		
	Lumpy	Lumpy	M1 Lump	M2 Lump + Fines	Ferruginous Lumpy
Mn	38	43-44	46	48	50
Fe	4-5	14-16	12-14	10-11	8-9
SiO_2	4-5	3-4	4-5	6-7	6-7
Al_2O_3	0.4-0.5	3-4	2-3	1-2	1-2
P	0.04	0.04-0.05	0.04-0.05	0.03	0.03

SOURCE: Weiss, 1977

A.11.1.2 Mamatwan

The Mamatwan mine, situated near the southern end of the Kuruman district, is mined by open-pit methods. It was started in 1961 on a reserve lease of 200 million m.t. drilled out on a 150 x 150 m or 200 x 150 m grid, with preproduction drilling grids reduced to a 60 or 75 m pattern (W. A. Preston, 1970). The ore horizon, which is the stratigraphically lower layer of manganese, averages 19 m thick, but attains thicknesses up to 46 m (Hammerbeck and Taljaardt, 1976). It is overlain by about 50 m of limestone that thickens northward and by more than 7 m of Kalahari sands. The sand is removed by a bucket-wheel excavator. Mining is by conventional methods utilizing drilling machines, large power shovels, front-end loaders, and rear-dump trucks. The annual production is about 1 million m.t. of product.

A.11.1.3 Middelplaats

This new mine(World Mining, 1979), situated near the south end of the Kuruman district and to the west of the Mamatwan, was put into production in mid-1979. The ore horizon lies at a depth below the surface of between 300 and 500 m, with the main operating level at 400 m. Access is provided by a vertical shaft and a 2500 m-long service ramp inclined at between 10 and 12° from the horizontal. The shaft is capable of hoisting 1.2 million tons of ore a year over a five-day week working cycle. The ore body, which is stratabound and dips northwest at about 10°, thins to the north and west. It will initially be mined in varying thicknesses of up to 14 m. The ore will be extracted in two or three cuts, using the room and pillar method of mining. Preliminary planning assumes a 75% overall recovery, with rooms and crosscuts mined 6 m wide and leaving 6 m square pillars.

The mining operation is highly mechanized. Twin-mounted hydraulic jumbos are used for drilling the ore prior to blasting. After blasting, LHD front loaders are used to collect and load the ore into 23.5 ton capacity rear-dump trucks for transport to the ore pass above the primary crusher station. The manganese ore is generally hard and competent and is composed of a mixture of oxides and manganese silicates including braunite and todorokite with gangue minerals including calcium and magnesium carbonates.

The exploration drilling was undertaken in two phases, with the initial spacing at 400 to 1000 m. Later this was reduced to a 300 m spacing throughout most of the deposit. Of the 24 holes drilled, 13 intersected the ore body. Some of the remainder were used to define the lava contact, while others were stopped due to mechanical or other difficulties. The results of the drilling delineated ore reserves in excess of 52 million m.t. at a grade of about 38% manganese, sufficient for a mine life of 30 years (W. A. Preston, presentation to the panel, 1979). The mine facilities are designed for an annual extraction of 1.5 million m.t. which by 1983 is expected to reach the planned annual production rate of 1.1 million m.t. of marketable product.

A.11.1.4 Beneficiation

At Wessels and Mamatwan, the run-of-mine ore is beneficiated by simple crushing and screening. The lump product is crushed to minus 63 mm with the minus 10 mm sizes being screened out and it may be expected that 15 to 20% of fines would be generated.

At Middelplaats, the primary crusher reduces the size of the ore to minus 150 mm. In the treatment plant a secondary crusher reduces the ore to 75 mm, after which it is fed to the washing and screening section for sizing. Typical lump ore product is sized at minus 75 mm plus 6 mm and fines at minus 6 mm plus 2 mm; about 15% fines are generated (Tex Report, 1977). The minus 2 mm fraction is further separated by cyclones into a minus 2 mm plus 150 m fraction that is dewatered and stockpiled. The minus 150 m fraction is thickened and pumped to a slime disposal pond.

A.11.1.5 Ore Persistence Character

The Kuruman District manganese-bearing basin has a north-south strike length of 41 km and a width varying from 5 to 20 km. The southern end of the field at Mamatwan may be terminated by a fault. From Mamatwan at the south end, the basin extends continuously northward for 34 km to the Black Rock and Wessels mines. Beyond Wessels the field extends discontinuously further northward as erosional remnants (Hammerbeck and Taljaardt, 1976). On the east side of the basin, erosional remnants of the manganese beds have been preserved in graben-like fault blocks where the Hotazel, Devon, and Langdon mines are located. Black Rock is the only outcrop of manganese ore occurring in the basin. The basin boundaries have been defined by magnetic surveys and by diamond drilling. The dip of the beds is to the west at about 15°, undulating in places, and flattening towards the center of the basin. Minor faulting and folding occur. Mineralization has been found at depths in excess of 1000 m in the center and western parts of the basin.

The manganese deposits of the Kuruman District occur as chemical precipitates. The protore is a laminated, fine-grained calcareous rock carrying about 27% manganese. It was originally deposited as a mixture of manganese hydroxide along with calcium, magnesium, and manganese carbonates (Hammerbeck and Taljaardt, 1976; Annhaeusser and Button, 1974). The formation consists of banded iron formation, with three manganiferous horizons near the base of the zone and calcareous dolomites higher up in the succession. The formation is in the Daspoort Stage of the Precambrian Transvaal System and it immediately overlies the Ongeluk lavas.

It appears that the basin is relatively manganese-rich along its eastern and east-central portions. The manganese content decreases downdip to the west, along with increasing carbonates such as manganocalcite or manganodolomite. Silica increases further to the west. Also in the eastern part of the basin, the manganese deposits tend to be thicker and more massive, while westward and northward there is a thinning and multiple interfingering of the manganiferous horizons.

The lower manganese layer that lies about 30 m above the Ongeluk lava can measure up to 25 m in thickness. The middle layer of protore is thin and impersistent, while the upper layer is some 6 m thick (Boardman, 1964; De Villiers, 1971). The lower and upper layers are not considered to be continuous (Boardman, 1964), but show lenticularity and are not always composed of manganese ore. There are discontinuities of unknown extent due to erosion and nondeposition. Lateral grade variations are to be expected.

In places, the banded iron formation is unconformably overlain by arenaceous and argillaceous rocks of the Waterberg System. Erosion during the Dwyka glaciation excavated a trough, which locally can be more than 500 m deep, and also removed a substantial amount of mineralization and, in places, the entire succession.

The near surface ore that was mined, at Hotazel, Smartt, Langdon, Devon, York, Adams, and Black Rock, shows that the calcareous protore has been upgraded by surficial processes, with the enrichment probably a multistage process. The various deposits are not uniform, but vary according to the layer of the protore being mined, the metamorphic grade imposed by bostonitic and gabbroic intrusives, the effects of hydrothermal action, and the intensity of surface enrichment processes (De Villiers, 1971; Anhaeusser and Button, 1974).

Metasomatic replacement and enrichment by manganese is a widespread phenomenon along zones of structural deformation. While surface enrichment is generally more pronounced in the surface zones, the effects of enrichment are noted at depth along joints, faults and folds in structurally disturbed areas such as part of the lower layer at Wessels. Here the ore contains up to 60% Mn compared with the 20 to 40% Mn in structurally unaffected areas between Mamatwan and N'Chwaning (Hammerbeck and Taljaardt, 1976).

The Kuruman manganese ores are mineralogically complex and variable and De Villers (1971) described 17 manganiferous minerals. The principal ore minerals appear to be braunite, bixbyite, hausmannite, jacobsite, todorokite, and cryptomelane. Featherstone (1975) gives the approximate composition of the Wessels ore as 33% braunite, 6% manganite, 32% hausmannite, 9% calcite, 1% magnesite, and 17% hematite. The Mamatwan ore has 48% braunite, 14% manganite, 22% calcite, 5% magnesite, and 6% hematite. No MnO_2 was found in either ore.

At Black Rock, two persistent ore bodies are developed, each of which is approximately 6 m thick and represents the upper and lower layers. The lower ore body has a uniform thickness downdip to about 130 m and gradually thins out to approximately 2.7 m at 300 m. The upper ore body is markedly lenticular and impersistent and transgresses across the laminations of the banded ironstone to the extent that in places it is in direct contact with the middle body (De Villers, 1971). It is ferruginous near the hanging wall and in places it is virtually a manganiferous iron ore (Boardman, 1964).

The Hotazel mine, which was preserved in the position by small-scale graben faulting, was mined from the upper and lower layers. The top was about 6-7 m thick and the lenticular middle 1.0 to 1.5 m. The lower 12 to 17 m bed was irregularly ferruginized and silicified.

At Mamatwan only the lower layer is being mined, but attains a thickness of up to 46 m.

A.11.1.6 Reserves

The ore reserves of the Kuruman District are the subject of much discussion as they represent one of the largest manganese resources. The problem of defining the ore reserve for the District is compounded by the fact that only a few companies have stated what their reserve base is.

The Anglo American Middelplaats reserve estimation (TEX Report, 1977) indicates that changing the cut-off grades influences the estimate greatly because the deposit has gradational hanging and footwall contact. The estimate is shown in Table A-20.

TABLE A-20. ANGLO AMERICAN MIDDELPLAATS RESERVE DATA AT VARIOUS CUT-OFFS

Cut-Off (%Mn)	Av. Thickness (m)	Tonnage (millions m.t.)	Mn (%)	Fe (%)	Ratio (Mn:Fe)
37	2.80	32.6	39	4.1	9.5
35	5.05	52.6	37.9	4.1	9.2
30	12.06	169.3	34.6	4.4	7.9

SOURCE: TEX Report, 1977

S. A. Manganese Ltd. has, at various times, published the reserve for their operating mines. In a 1970 company brochure, the proven ore reserve was given as: Wessels 50 million m.t.; Mamatwan 200 million m.t.; and other deposits, not defined, as 200 million m.t. Featherstone (1975) gives the ore reserve in 1975 as being: Wessels 50 million m.t. and Mamatwan as 50 million m.t. proven; 200 million m.t. probable, and 400 million m.t. possible.

It is also stated that the Wessels mine has a life of over 50 years and that of Mamatwan over 200 years. Therefore, it may be presumed that for Wessels to operate for 50 years, the reserve must be a minimum of 135 million m.t. of in-place ore to produce 75 million m.t. of product, assuming a yearly production of 1.5 million m.t. Allowance has been made for mining recovery and fines loss. Estimates of the Samancor reserves within the Kuruman District are given in Table A-21.

TABLE A-21. SAMANCOR KURUMAN DISTRICT RESERVES ESTIMATES (million m.t.)

Wessels Grades (+44% manganese)	184.8 proven 6.0 inferred 190.8
Mamatwan Grades (38 to 40% manganese)	328.0 proven 105.0 inferred 433.0
RESERVE TOTAL	623.8

SOURCE: Rheeder, 1978.

Ammosal does not publish reserve data; however, an estimate can be made for the four operating underground mines at Black Rock, N'Chwaning, Gloria, and Perth. If it is assumed that the mines have a 30-year life and that production will be at or exceed 2.5 million m.t. per year, then a reserve within the above grade categories would be a minimum of 134 million m.t. Rheeder (1978) has made an estimate of the Ammosal reserve within the same categories as 120 million m.t. at Wessels grades and 509 million m.t. at Mamatwan grades.

The total demonstrated plus inferred in-place ore reserve for the Kuruman could be, using the various estimates, as shown in Table A-22.

TABLE A-22. COMPARATIVE ESTIMATES OF KURUMAN RESERVES (million m.t.)

	Panel Estimates	Mainly after Featherstone	Mainly after Rheeder
Middelplaats	52.6	52.6	52.6
Samancor	623.8	700	623.8
Ammosal	134	134	629
TOTAL	810.4	886.6	1,305.4

SOURCES: Featherstone, 1974; Rheeder, 1978.

The best conservative estimate based on the information available is considered to be the reserve tonnage of 886.6 million m.t. This reserve would yield approximately 248 million m.t. of contained manganese.

About 1200 holes have been drilled within the basin (C. Sweetwood, Regional Resources Offices, U.S. Consulate, reply to Committee questionnaire), most for preproduction information. The remainder are on widely spaced centers. The possible extensions to the west and to the north, under cover of the Kalahari sands, have been tested. No major extensions have been located.

A.11.1.7 Resources

The resources of manganese in the Kuruman District are undoubtedly large. Some of these have been defined by diamond drilling and the remainder by geological projection of the known mineralized layers. The amount of resources and their breakdown into paramarginal, submarginal, and hypothetical categories depends on many variables, including grade, chemistry, or type of salable product, and depth, minability, mining costs, and capital costs. The submarginal resources are the lower-grade material that occurs within the central part or the west-central part of the basin where the mineralization has been found at depths exceeding 1000 m. It has also been mentioned previously that the mineralized layers are not thought to be continuous and that lateral grade variations are expected to occur.

The estimated resources given by Rheeder (1978) are shown in Table A-23, with an adjustment for Middelplaats and the addition of the resource categories.

The total resource in all categories is 10,197 million m.t. of in situ mineralization, of which as much as 50% may not be minable. The recoverable contained manganese in the resource tonnage estimate should be considered within the two grade intervals as given in the estimate. The combined 5,897 million m.t. have a small amount of Wessels grade material and the remainder of Mamatwan-Middelplaats type material, i.e., with low iron probably suitable for the production of ferromanganese.

The 20 to 30% grade resource material, which is below the lower limits of the material being considered, may be a different situation. There is no reference to any recent work being done to upgrade this material. The overall chemistry and mineralogy are relatively unknown. There is one drill hole on Olive farm, with a zone of mineralization at about 1000 m that has an analysis of 28% Mn, 9.4% Fe, and 9% SiO_2. There is no reliable evidence to indicate whether this material is suitable as metallurgical grade material. The basin is described as having a higher carbonate content to the west, with increasing silica. There is no information as to whether the silica occurs as part of a silicate mineral or as free quartz. However, it may be expected that the mineralization would require an increased amount of beneficiation, most likely at the expense of recovery, in order to upgrade it.

TABLE A-23. ESTIMATED RESOURCES IN THE KURUMAN DISTRICT (million m.t.)

Grade - 30 to 44%	48	(Wessels Grades, High Fe)
Grade - 30 to 38%		
Samancor	614	proven (paramarginal)
	2,166	inferred (hypothetical)
Subtotal	2,780	
Ammosal	1,913	estimate (75% hypothetical)
Iscor	347	estimate (submarginal/paramarginal)
Minerts	693	estimate (submarginal/paramarginal)
Middelplaats	116	indicated
Total	5,897	
Grade 20 to 30%		
Samancor	200	proven (submarginal)
Samancor	1,660	inferred (hypothetical)
Subtotal	1,860	
Ammosal	1,400	estimate (90% hypothetical)
Iscor, Minerts	1,040	estimate (submarginal/hypothetical)
Total	4,300	

SOURCE: Rheeder, 1978

The recoverable contained manganese in the 30+% paramarginal/submarginal material is estimated as 838 million m.t. manganese. The tonnage in the submarginal/hypothetical material is estimated as 377 million m.t. The total is 1,215 million m.t. of recoverable contained manganese.

In the information provided from the International Iron and Steel Institute's questionnnaire on manganese (IISI, 1980), Samancor reserves are shown as 629 million m.t. containing 254 million m.t. of manganese (40.5% Mn), which is consistent with the other "hard data" herein presented. Samancor's resources are shown as 4,688 million m.t. containing 1,439 million m.t. manganese (30.6% Mn). This resource figure is a large part of the total material figure for South Africa and is consistent with the classification given above. It is a considerable part of the total material figure for South Africa, which the Minerals Bureau of the Republic of South Africa (Neethling, 1979) (with no qualification) calls "identified reserves" and which the South African Geological Survey calls the "total identified reserves as defined by McKelvey."

A.11.2 Postmasburg District

The Postmasburg District in the Northern Cape Province extends northward from Postmasburg for about 65 km to Sishen and may be divided into a western and eastern belt. This district is made up of a series of irregular epigenetic/replacement deposits grading from ferruginous manganese as low as 20% Maganese to high-grade ores at 50% Maganese (W. A. Preston, British Steel Corporation, presentation to the panel, 1979). Due to the drop in grade, adverse mining conditions, and the gradual weakening in the demand for siliceous manganese ore such as occurs in the eastern belt, production was curtailed there in favor of the western belt (Hammerbeck and Taljaardt, 1976).

The open-pit Lohatlha mine, owned by S. A. Manganese Ltd., produces about 500,000 m.t. per year of product, with a typical analysis of 28 to 30% Mn, 24 to 26% Fe, 3 to 5% SiO_2, 6 to 8% Al_2O_3, 0.3% CaO, 0.4% MgO, 0.05% P, and 0.03% S (Weiss, 1977; Preston, presentation to the panel, 1979).

The Gloucester, Bishop, and Glossan mines owned by Associated Manganese of South Africa are also open-pit mines and have an estimated production of 300,000 m.t. of product per year, with grades and analyses similar to those of Lahatlha. The open-pit Rooinekke, owned by Consolidated African Mines Ltd., produces about 200,000 m.t. annually of manganiferous iron ore grading 18 to 20% Mn, 34 to 36% Fe, 12% SiO_2, 2.5% Al_2O_3, and 0.09% P.

The Lohatlha manganese ore is developed in the lower part of a 30m-thick shale layer that is capped by quartzite. The ore lies in contact with the underlying dolomite, occupying sink holes and pockets between pinnacles on a karst surface of the dolomite. The ore bodies are not of great size. In general, the hard nature of the ore allows a good recovery factor, which yields a salable product. Some washing of the Lohathla 28 to 30% Mn crude ore is required to provide the 35 to 45% Mn products (Preston, presentation to the panel, 1979).

A.11.2.1 Ore Persistence Character

The western belt is characterized by ferruginous ore types that occur close to the unconformable contact of the Gamagara Formation overlying Campbell Rand Dolomite. This low-dipping contact has a sinuous outcrop pattern mainly due to the slumping of the Gamagara beds into solution depression in the dolomite. The ores are only developed where the Gamagara Formation rests directly on the dolomite. They are thought to have formed by near surface leaching of manganese from the dolomite and replacement of the Gamagara shale by the manganiferous solutions. The manganized shale is frequently overlain by, and grades into, variable thicknesses of hematized shale. Slumping of the manganized shale into dolomite solution depressions has resulted in the ore being fragmented into disjointed blocks set in an earthy fill (Anhaeusser and Button, 1974). One of the main sources of manganese presently being exploited is the detrital ore occurring in soil at the foot of elevated ground on the Lohathla farm. The principal manganese mineral in these deposits is bixbyite with jacobsite, braunite, hausmannite, pyrolusite, lithiophorite, and partridgeite.

The eastern belt mineralization is found at or near the contact of a pre-Gamagara residual chert breccia and the underlying Campbell Rand Dolomite. It consists principally of braunite with lithiophorite, psilomelane, and hausmannite. The main gangue mineral is silica from the chert breccia. The mineralization is extremely irregular and limited to depths of 30 m (Anhaeusser and Button, 1976), in steep, irregular, pothole and solution channels.

A.11.2.2 Reserve

The 1978 estimate of the reserve has been given as 15 million m.t. grading 28 to 30% Mn (Rheeder, 1978). The reserves cannot be assessed, with any degree of accuracy, by drilling. There is a good possibility of developing further but limited reserves of similar grade material.

A.11.2.3 Resource

The irregular form of the deposits does not allow any overall resource value to be applied to this district.

A.11.3 Minor Deposits

Transvaal-Dolomite Series. Manganese in the Transvaal occurs in numerous localities from the west and northwest of Krugersdorp to the border of Botswana. Sporadic occurrences of pyrolusite and manganiferous earth or wad are found widely scattered in those areas underlain by the dolomite series. The manganese occurs as surficial enrichment in deeply decomposed surface material during weathering of the dolomite (De Villiers, 1960).

The deposits are all small and few are of economic interest. About 13 companies operate about 12 open-pit mines and one (the Gopani mine near Zeerust) underground mine. The total output is about 200,000 m.t. per year and the production is for specialized usage of MnO_2 in uranium extraction and for the battery, chemical and pigment industries (Preston, presentation to the panel, 1979). There are several grades produced, i.e., 62.5 to 70% MnO_2 battery grades and with chemical grades in several intervals from 35 to 40% Mn to 70 to 85% MnO_2. Reserves and grades are quoted as 150,000 m.t. at 45% MnO_2 in the Rand Mines and the rest of the ore varying between 60 and 70% MnO_2 "uranium grade" and a 42 to 47% Mn "lumpy grade" (Preston, presentation to the panel, 1979). The reserves are presumed to be small. The resource of the low-grade wad mineralization could be several millions of tons.

Transvaal-Waterberg System. This system, which is principally to the north of the Dolomite Series, has gash-vein fillings, fault and shear-zone impregnations, and localized concentration of psilomelane, with minor braunite in red and purple ferruginous sandstones. The deposits are either small or of a poor grade and are not economic (De Villiers, 1960).

Cape Province. Manganese mineralization, usually pyrolusite and psilomelane, is found as veins and impregnations in quartzite and sandstones of the Table Mountain Series in the western and southwestern Cape Province. The deposits seldom persist in depth and generally have a high phosphorus content so there is no current production. The resource is considered to be small.

REFERENCES

Anhaeusser, C.R. and Button, A., A Review of Southern African Strataform Ore Deposits--Their Position in Time and Space, Information Circular No. 85, Economic Geology, Research Unit, Union of the Witwatersrand, South Africa, pp. 33-34, April 1974.

Boardman, L.G., Further Geological Data on the Postmasburg and Kuruman Manganese Ore Deposits, Northern Cape Province, Some Ore Deposits of Southern Africa 2, Geological Society, Johannesburg, pp. 415-440, 1964.

Conin, E.R., Ferrous and Non-Ferrous Mines and Works in South Africa, Directory No. 3/79, Department of Mines, Minerals Bureau, Johannesburg, January 1979.

De Villiers, J., The Manganese Deposits of the Union of South Africa, Geological Survey of South Africa, Handbook 2, Pretoria, 1960.

De Villiers, P.R., The Geology and Mineralogy of the Kalahari Manganese Field North of Sishen, Cape Province, Geological Survey of South Africa, Memoir 59, Pretoria, 1971.

Featherstone, R.A., Applications of Mamatwan Manganese Ore, Proceedings of INFACON 1974, Ed. H. Glen, The First International Congress on Ferro-Alloys, South African Institute of Mining and Metallurgy, Johannesburg, pp. 263, 273, 1975.

Geological Survey Bulletin 1450-A, Principles of the Mineral Resource Classification System of the U. S. Bureau of Mines and U. S. Geological Survey, U. S. Bureau of Mines and U. S. Geological Survey, Washington, D. C., 1976.

Hammerbeck, E.C.I. and Taljaardt, J.J. Manganese in Mineral Resources of the Republic of South Africa, Geological Survey of South Africa, Handbook 7, Ed. C. B. Coetzee, Pretoria, 1976.

Middelplaats Manganese Ltd., Provisional Specification Sheet for Middelplaata Washed Metallurgical Manganese Ore., Middelplaats Manganese Ltd., Johannesburg, October 6, 1978.

Neethling, D.C., Letter to C. Sweetwood entitled "South Africa's Manganese Ore Reserves and Grades." U.S. State Department Telegram 248953, Republic of South Africa, Department of Mines, Minerals Bureau, Braamfontein, South Africa, p. 6, October 5, 1979.

Rheeder, O.F., Manganese Resources Based on the Testimony of Robert L. L'Esperance. Memorandum to Dr. T. F. Muller, Samancor, S.A. Manganese Amcor Ltd., Johannesburg, June 22, 1978.

S.A. Manganese Amcor Ltd., Kalahari Wealth -- The Story of Manganese 1926-1976. Purnell and Son (S.A.) Pty. Ltd., Cape Town, 1977.

S.A. Manganese Amcor Ltd., Samancor, Johannesburg, 1978.

Republic of South Africa, Statistical Summary of Mineral Production, 1972-1978, (annual statistics for year involved), Department of Mines, Minerals Bureau, Johannesburg.

The TEX Report, Existing Status of AAC Manganese Mines Development Project (1), The TEX Report 9/2090, 4, and 9/2091, September 12, 977 and September 13, 1977, respectively.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books Ltd., Garden City Press Ltd., Hertfordshire, U. K., 1977.

World Mining, Middelplaats Underground Mine is Highly Mechanized, Vol. 32 pp. 52-55, November 1979.

A.12 UPPER VOLTA

Occurrences of manganese are fairly numerous in Upper Volta, but only a few are important. They appear to be similar to those found in neighboring Ivory Coast and Ghana. In this part of western Africa, manganese occurs mainly as metamorphosed manganiferous sediments that form part of the Middle Precambrian, "Birrimian" volcano-sedimentary greenstone belts. The manganese, plus associated silica and iron, had their source in submarine volcanics and were deposited, more or less mixed with detrital minerals, as syngenetic chemical precipitates.

The original manganese-bearing constituents of these sediments may have included oxides, silicates, and carbonates, with subsequent folding and metamorphism resulting in "gondites." The latter are siliceous sediments containing in general some 25 to 30% manganese that occurs mainly as silicates, in some cases associated with carbonates. According to the original grade and composition of these protores and to the local circumstances of later weathering, supergene deposits of Mn-oxides have been formed that range from mere showings to sizable Mn-oxide deposits. It appears that in the latter, the protore almost always contains considerable quantities of manganese-carbonate and this is presumably a prerequisite for the formation of such deposits. Thus, carbonate ore is present in depth at all the noteworthy deposits in West Africa, such as Nsuta (Ghana), Mokta (Ivory Coast), Tamboa (Upper Volta), and outside this immediate area at Kisenge (Zaire).

A.12.1 The Tamboa Deposit

This is the largest known manganese deposit in Upper Volta. It is located in a remote area in the northeast extremity of this land-locked country, some 350 km from the capital, Ouagadougou. The deposit is part of a small, isolated patch of metamorphosed volcano-sedimentary formation surrounded by granitic rocks. The formations strike north-northwest and dip 45 to 70° to the east. The manganiferous layers form the backbones of two elongated hills that measure respectively 1,550 m long by 350 m wide, with a relief of 77 m above the surrounding peneplain, and 850 m by 200 m with a relief of 44 m. The volcano-sedimentary formation consists of schists and tuffs, with a thin intercalation of basic volcanics and several thin intercalations of quartzite. It includes four manganese-bearing beds which vary in thickness between 4 and 28 m. Below the zone of supergene oxidation, this material consists of manganese carbonate, spessartite, and other manganese-silicates.

This so-called "carbonate ore" at depth comprises three types:

- Material with predominant rhodochrosite containing an average of 48% manganese (presumably also contains high-grade primary oxides);
- Material with predominant Kutnahorite (Ca, $MnCO_3$) containing an average 36% manganese; and
- Material with predominant "hydrohausmannite" (a "primary" manganese-oxide) and associated carbonates, averaging 55% manganese.

The "carbonate ore" contains less than 1% Fe, 7 to 9% SiO_2, less than 0.01% P, and minor amounts of sulfides (pyrite, molybdenite). Besides the minerals mentioned, it contains some "primary" silicates and oxides of manganese (tephroite and hausmannite) and minor, secondary oxides such as cryptomelane and manganite.

Extending upward to the surface over a depth on the order of 70 m, the carbonate ore becomes more and more oxidized, with the development of supergene oxides (crytomelane, pyrolusite, and n'sutite or battery grade ore) as the main minerals. This oxidized zone comprises:

- Chemical ore with 56 to 60% manganese that comprises the main manganese layer;
- Rich metallurgical ore with 48 to 54% manganese; and
- Metallurgical ore with 44 to 48% manganese.

The average grade of all oxide ore is 53.88% manganese. Further, this material contains 1 to 2% Fe, 2 to 5% SiO_2, 5 to 9% $Al_2O_3 + SiO_2$, and 0.13 to 0.18% P.

A.12.1.1 Resources

The deposit was discovered in 1960 by the French Bureau de Recherches Geologiques et Mimieres (B.R.G.M.). Prospecting of the oxide ore (mapping, tunneling, sampling) in 1963 indicated the existence of 10.5 million m.t. at 51% manganese, including 4 million m.t. proved, 5.5 million m.t. probable, and 1 million m.t. of detrital ore.

The deposit was further investigated (drilling, tunneling, pitting, and geophysical prospection) by the United Nations between 1966 and 1970. This led to a resource estimate of 16.1 million m.t. at 53.8% manganese, of which 10.14 million m.t. were over 54% manganese, 4.99 million m.t. 48 to 54% manganese, and 0.97 million tons at 44 to 48% manganese. About 12.6 million m.t. of the total are oxide ore and 3.5 million m.t. represent a mixture of oxides and "rich carbonate" ore. The resources comprise 11.5 million m.t. measured, 3.2 million m.t. indicated, and 1.4 million m.t. inferred.

Moreover, eluvial, detrital ore that locally covers the hills was estimated to be 730,000 m.t. at 49.8% manganese. This material is not included in the total resource of 16.1 million m.t.

The resources of oxide ore would be minable by open-pit with a ratio of overburden to ore of about 1.79 to 1. The deeper carbonate ore constitutes a subeconomic resource at the present time and no reliable figure is at hand. Although there is significant quantity of very high-grade ore, there are obstacles to mining. The area is remote and lacks water, power, and transportation facilities. Even so, commercial development by a "five-nation-thirteen-companies" consortium is under study. The consortium is composed of several Japanese interests, the West German Exploration und Bergbau, the French Societe du Manganese, the BRGM and the government of Upper Volta.

Initial production may take place in the 1980's with 625,000 tons per year. About half of this will be exported to Japan, and small quantities to the United States, France, and West Germany. From the data given above, it would appear that the major part of the production at first will consist of chemical- and battery-grade ore. The project includes development of power and water facilities and either the construction of a 353-km-railroad to Ouagadougou or haulage by trucks to the capital. There is an existing railroad from Ouagadougou to the port of Abidjan (Ivory Coast), the total distance from the deposit to the sea being some 1,200 km.

A.12.2 The Tiere Deposit

This deposit is located some 270 km southwest of Ouagadougou, within 10 km of the railroad to Abidjan. It occurs in low-grade metamorphic Birrimian sediments (phyllites, tuffs, quartzites), associated with sheared andesites. Over a length of some 20 km toward Hounde, this formation contains occurrences of manganese oxides that are associated with spessartite-bearing quartzites. Of these occurrences, the Tiere deposit is the only one of any importance. It is on the crest of a small hill some 80 m above the surrounding plain, forming two lenticles with a total length of 500 m and a width of 15 to 30 m. A third, much smaller lens is located farther southeast.

The deposit was prospected by the French Geological Survey of West Africa and by the BRGM, with mapping, trenching, and some tunneling, between 1943 and 1954. These investigations did not find any carbonate type protore. Pyrolusite, cryptomelane, and other Mn-oxides are the result of alteration of spessartite-bearing quartzite. All transitions exist between this gondite and ore. Supergene alteration may have been facilitated by the presence of a strong east-west fracture system.

The supergene ore is high in silica (over 30% SiO_2), while the average manganese content is between 25 and 30% manganese. The ore includes two small lenses some 40 m and 25 m long, respectively, that may contain some 40 to 45% manganese. It has been estimated that if the ore could be successfully beneficiated, the possible tonnage of a marketable manganese product could eventually be about 900,000 m.t. at 46 to 48% manganese and 11 to 13% SiO_2. However, the proved reserves amount to only 300,000 m.t. and are reported to contain 30 to 45% manganese. It is clear that this deposit is no more than a small resource.

A.12.3 Other Occurrences of Manganese

All other known occurrences of manganese are without any economic interest. They are mostly mere showings of manganese oxides, often rich in iron. A deposit at Soukoura, for instance, contains 29.5% manganese and 15% iron. Other occurrences are known at Gonsponson, Kangoussi, Kakoi, Kori, Kayo-Koti, Boniri, Kalgo, Duo, and Kalye-Kadeini. The chances of locating another important manganese oxide deposit of the volcanogene-sedimentary type at the surface must be rated very low. In view of the conspicuous nature of manganese oxides, which tend to accumulate along hill crests, it may be presumed that several decades of prospecting does not leave much space for new discoveries. Theoretically one can speculate on the existence of hidden deposits of carbonate ore that are below the surface and were never oxidized and enriched.

REFERENCES

de Kun, N., The Mineral Resources of Africa, Elsevier Scientific Publishing Company, Amsterdam, Holland, 1965.

Miscellaneous news items on the Tamboa deposit, Engineering Mining Journal, Metals, Sourcebook, and World Mining, various issues, 1973-1976

Michel, H., Manganese Ore in Ghana, Internal Report, Geology Department, Bethlehem Steel Corp., 1974.

Michel, H., Manganese in Ivory Coast, Internal Report, Geology Department, Bethlehem Steel Corp., 1975.

U.S. Bureau of Mines, Upper Volta. Minerals Yearbooks, U.S. Government Printing Office, Washington, D. C., 1960-1972.

A.13 ZAIRE

The Kisenge-Kamata-Kapolo deposits that were discovered in 1927 and explored in 1939 are located in the southwest of Shaba Province in southern Zaire. They are 28 km to the southeast of the Tenke-Dilalo (Benguela) railway line. The shipping distance to the port of Lobito Bay, Angola is 1,484 km.

Mining of the oxide reserves from the Kisenge and Kamata Principal deposits was started in the early 1950's. The mines produced almost continually until 1977, the last year of exports. Stoppage was due to internal problems of Zaire and the problems of Angola, through which the Benguela Railway passes.

At a normal operating level, annual mine open-pit production is 1.2 million m^3 of material at a stripping ratio of 2.33 m^3 of waste to 1 m.t. of ore (W. A. Preston, British Steel Corporation, presentation to the Committee, August 1979). Up to 1976, production capability was rated between 300,000 to 350,000 m.t. per year, of which 10,000 m.t. is chemical grade and the rest metallurgical. The average yearly production from 1956 to 1975 is about 328,000 m.t. Some carbonate ore was being produced.

The initial proven reserve was given as 8 million m.t. at a nominal grade of 51% manganese. In 1972 the second pit opened to produce at this grade encountered a sharply defined oxide-carbonate contact at about 20 m depth. A third ore body which was opened by open-pit in 1973, averaged 51% manganese, comparable to the first two ore bodies, but required selective mining to maintain this grade. Table A-24 shows production by grade.

Beneficiation consisted of a crushing, screening, and blending plant rated at 150 m.t. per hour of product and also a 100 tph heavy media plant to treat 35 to 42% manganese grade material. The overall crude ore weight to product weight recovery is about 63% (W. A. Preston, presentation to the panel, 1979).

The manganese deposit has been divided into four zones, namely Kisenge, Principal Kamata, Kamata left side, and Kapolo. The ore crops out in the form of elongated hillocks of variable dimensions running in an east-west direction, with the relief due to the hard manganese-oxide cappings. The silicate (gondite) and carbonate deposits are primary sedimentary deposits in a series of Precambrian sericite schists and quartzites, with amphibolitic schists to the south that have been intruded by granite. Pegmatitic intrusives exist, both in the mineralized manganese zone and to the south of it. The metasediments are strongly folded with variable dips to the south and have suffered medium- to high-grade metamorphism.

TABLE A-24. ZAIRE MANGANESE PRODUCTS GRADES AND THEIR ANALYSES (%)

Type	Mn	MnO_2	Fe	SiO_2	Al_2O	P	Lumpy Size
Grade R.A.	50-57	2-3	6-7	5	0.13-0.12	70%	10-150 mm
Grade R.AX.	55	74	1.19	2.08	4.80	0.116	15% 6-10 mm
Grade R.C.	56	82.90	1.18	1.26	2.30	0.144	15% below 6 mm
Grade G.B.	48-50	70-72	3.4	6-7	6.5	0.12-0.13	1-10 mm
Carbonate	39.03	1.29	0.83	8.27	n.a.	n.a.	10-150 mm

*CaO 4.58%, MgO 2.00, LOI 27.96, Cu 0.032%, Ni 0.142%, Co 0.042%

*Minor and trace elements in the carbonate product.
n.a. - not available

SOURCES: Weiss, 1977; Doyen, 1973.

The manganese oxides, psilomelane, and pyrolusite, with lesser hollandite and polianite, occur as superficial, enriched, residual cappings on either gondite (Kisenge) or manganese carbonate (Kamata), and have vertical depths of up to 50 m.

The Kisenge silicate deposit is formed by alternating garnetiferous and graphitic schists. The enclosing rocks are highly metamorphosed quartzite and mica schists. The primary ore is represented by a gondite of a garnet schist type that has a manganese content below 20%.

At Kamata, drilling has encountered lenticular manganese-carbonate deposits in depth. These strike east-west and dip at 45 to 70° south. The manganese carbonate, which is primarily rhodochrosite, grades about 40% manganese. Graphitic carbonaceous matter and garnet are almost always associated with the carbonate. The carbonate that often contains inclusions of braunite, bixbyite, and manganite, has not been fully developed by drilling.

In 1972 the reserve (Preston 1979) was quoted as being 3.5 million m.t. of metallurgical grade ore at 42.85% manganese, 120,000 m.t. of chemical- and battery-grade ore at 54.16% manganese, and 10 million m.t. of carbonate ore at 40% manganese. It is assumed that the current metallurgical reserve is about 1.2 million m.t. of crude oxide ore. It was announced in April 1977 that 8 million m.t. of crude ore, concluded to be carbonate resource, occurs at 35 to 40% manganese.

The oxide ores are nearly exhausted, but would support a normal operation for a little over two years. Further oxide discoveries are not thought probable. Most of the carbonate deposits would require underground mining which, considering their remote location, probably would be uneconomical. These deposits have not been fully explored. The silicate bodies are not probable producers of manganese.

REFERENCES

Angola, Zaire, Zambia Reach Benguela Pact, American Metals Market 87/77, p. 8, April 19, 1979.

Doyen, L., Etude Metallogenique des Gisements de Manganese de Kisenge-Kamata-Kopolo., Doctor of Sciences Thesis, Universite Libre de Bruxelles, Unpublished, February, 1974.

Doyen, L., The Manganese Ore Deposits of Kisenge-Kamata (Western Katanga): Mineralogical and Sedimentological Aspects of the Primary Ore, Ores in Sediments, Eds. G.C. Amstutz and A.J. Bernard, International Union of Geological Sciences, Series A, Number 3, Springer-Verlag, New York, pp. 93-100, 1973.

Schuiling, H. and Grosemans, P., Les Gisements de Manganese du Congo Belge, Symposium on Manganese, Vol. II, Africa, 20th International Geological Congress, Mexico, pp. 131-142, 1956.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books Ltd., Garden City Press, Ltd., Hertfordshire, U. K., 1977.

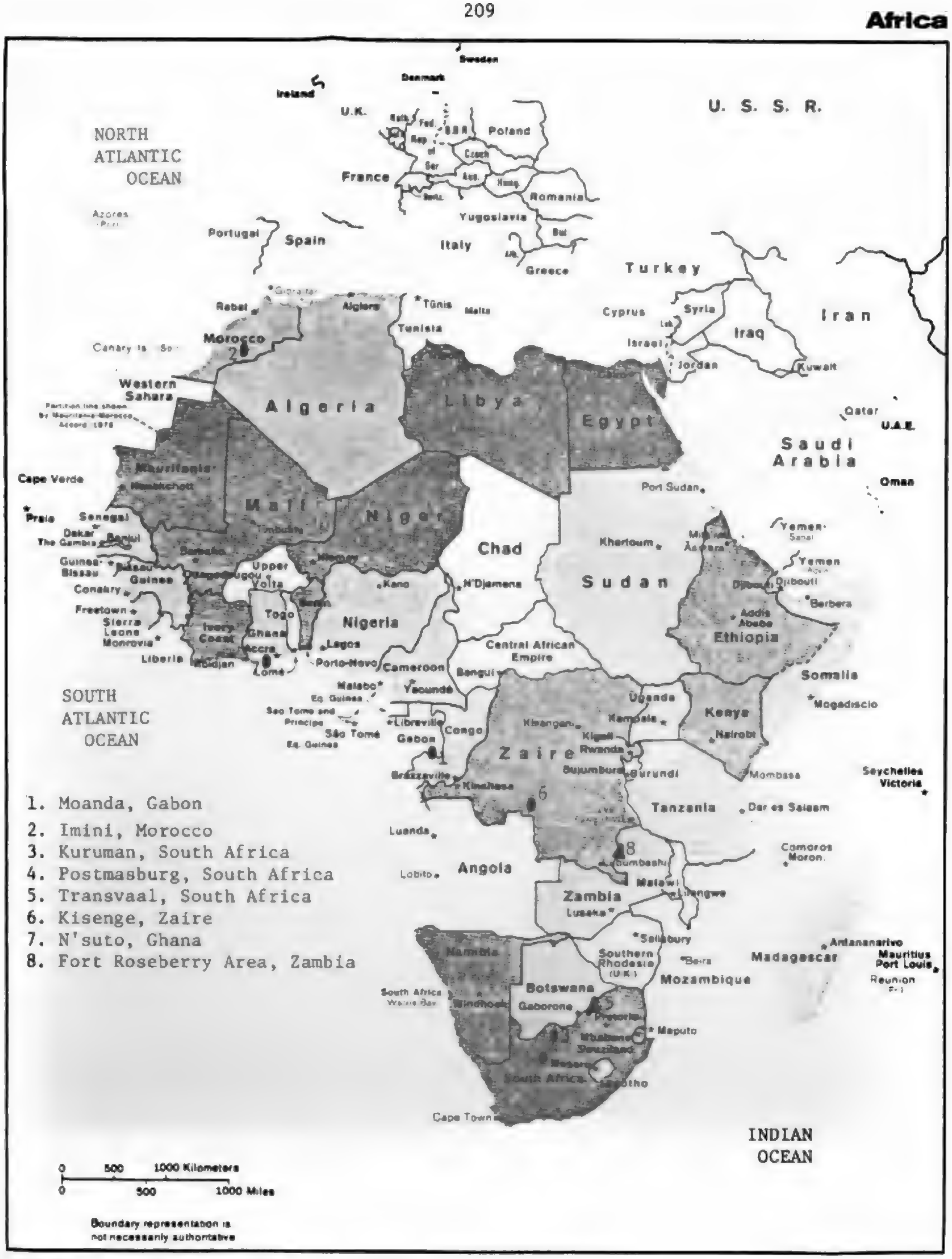


FIGURE A-8. Manganese Mines in Africa

ASIA

A.14 PEOPLES REPUBLIC OF CHINA

China has been producing manganese ore for more than 60 years. The annual production for the last several years has been estimated by the U.S. Bureau of Mines at 1 million m.t. of plus 30% manganese. Argall (1979) estimates that the Chinese production of manganese for 1978 had 300,000 to 400,000 m.t. of contained manganese.

Principal production of manganese from the provinces south of the Yangtze River has been near Hsiangtan and Ningyuan in Hunan; Mukuei, Laipin, and Wu-hsuan in Kwangsi; Tsunyi in Kweichow; Chin Hsien and Fangcheng near the Luichow Peninsula in Kwangtung; and Chienchi near Nanking. North of the Yangtze River the principal manganese production has been from lower-grade deposits at Wafangtzu in Liaoning Province. The production comes from a large number of small operations, presumably unmechanized, that on the average produce 20,000 tons per year each.

China is not an important factor in international trade of manganese ores for production of ferroalloys. About 90% of production is consumed domestically; this includes ferruginous manganese ore. It exports to Japan about 50,000 m.t. annually of ferruginous manganese ore with 25 to 28% Mn 17% Fe, and somewhat high (0.2%) P. Since little of the Chinese ore is high-grade, except minor production from enriched oxide sections of carbonate deposits, it is to be expected that the Republic makes more spiegeleisen than ferromanganese. The carbonate ores are beginning to be calcined to nodules with 35 to 47% manganese for local use. China is importing medium-carbon ferromanganese from Japan.

The reserves have been estimated (Ikonnikov, 1973) as "not less than 130 million metric tons" of ore averaging less than 40% contained manganese. Varentsov (1964) estimated the reserves of contained manganese to be 44 million m.t. divided as follows: 28 million m.t. associated with the Sinian age rocks in Kiangsi and Hunan provinces; 4 million m.t. of manganese associated with the Rifian rocks of Liaoning Province; and 12 million m.t. of manganese with the carboniferous rocks of Kiangsi Province. All of those occurrences are associated with the orthoquartzite siliceous shale carbonate rock suites of platform areas of moderate- to high-tectonic activity (Varentsov, 1964).

Large reserves of ore quoted at tens of millions of tons of ferruginous manganese with cobalt and nickel are reported in the Tsunyi District in Kweichow Province. Also, the reserves at Wafangtzu in Liaoning Province are reported to contain 16 to 18% iron, thus placing them in the category of ferruginous manganese and excluding them from the classification of manganese ores proper. Of all the reserves, 63% are located in the southern provinces. In addition to the quoted reserves that are associated with marine sedimentary rocks, there are other smaller occurrences of manganese in hydrothermal-metasomatic deposits from which small tonnages of 45 to 48% manganese have been produced.

In reviewing China's deposits, it became apparent that a considerable amount of the material described was ferruginous manganese ore not within the charge to the panel. A Chinese review of the possibilities of finding more and better deposits suggests that there are minimal descriptions of the pre-Revolution occurrences and that these received little methodical development in advance of mining. Post-Revolution discoveries have been better examined and described. The Chinese believe their best possibilities for high-grade ore may exist in the subtropical south, while the best chances for large, potential occurrences would be in the marine sedimentary carbonate deposits of several areas of China, both in the south and the north. The reserve figures result from a judgment by the panel regarding the amount of material that falls within its review scope.

In conclusion, China's potential is not well known. If further discoveries result, there is more likelihood that the larger ones will be marine-sedimentary, probably more carbonate than oxide, and thus of rather low grade. The details of the manganese occurrences are listed in the synoptic Table A-25. When using this table, the reader is cautioned about the identification and spelling of geographic place names that vary among the quoted references and vary between the older publications and the newer ones using Pinyin Romanization spellings. (The Pinyin Romanization spellings are included with the Provincial names in the Synoptic Table A-25.)

Table A-25. Synopsis of Known Manganese Occurrences—People's Republic of China

Name Area–Province	District	Chem. Constituents–% Mn	 SiO_2	 P	 Fe	Mining Characteristics	Persistence Characteristics	Remarks	Ref.
NORTH CHINA Hopeh Prov. *(Hebei)*	1) Chi-hsien	28	35 *	–	–	There are 4 ore beds of which the uppermost is more or less bedded and the most persistent. The other three are irregular and lenticular. The ore beds are thin.		1) The Chi-hsien district is 90 km E of Peking; the manganese deposits occur in the lower part of the Sinian age Kao-yu-Chuang formation. The Mn beds are underlain by cherty limestones and sandy shales and are over lain by limestones and dolomites. The Mn section is 50 m thick, increasing to 120 m westward. It consists of calcareous and siliceous manganese ores and manganese bearing limestones. The basal and the upper parts consist of Mn-bearing limestones. There are 4 ore beds of which the uppermost is the most persistent. The dense part of the ore consists of needles of pyrolusite and blocky psilomelane, to unknown depths. *The 35% "SiO_2" is 35% acid insoluble residues. Reserves are "medium", i.e. 1-10 MMT.	1 (p. 318) 2 (p. 837)
	2) Changping	N.A.						2) *Changping* district, 40 km NW of Peking and includes Tiehkuangliang and Hsiachung deposits.	1 (p. 318)
	3) Lingshou	N.A.						3) *Lingshou* district, 250 km SW of Peking. Reserves are less than 1.0 MMT (small).	1 (p. 318)
Shansi Prov. *(Shanxi)*	1) Lucheng	N.A.						1) *Lucheng* district located 170 km south of Taiyuan. Deposits are of limnic sedimentary type. Reserves are less than 1.0 MMT ("small").	1 (p. 320)

	2) Other							2) *Other*. Chao (Ref. 2) reports a number of sedimentary lenticular and small manganese oxide orebodies scattered throughout the province. They are of marine-Lacustrine origin and are associated with Permian sandstones and sandy shales. The tenor and thickness of the ore varies greatly. The ore contains 10% Mn, 23% Fe, 25% SiO_2 (large as opal) and 0.3-0.6% Phos.	2 (p. 840)
NORTHEAST CHINA									
Liaoning Prov. *(Lianoning)*	1) Wafangtzu	17-32	*	*	*	Bedded deposits less than 2 meters thick.	Marine sedimentary; manganiferous beds traced for more than 20 km along strike.	1) The *Wafangtzu* district is located about 280 kms. west-southwest of Shenyang and west of Chin-hsien. Three manganiferous beds which are all less than 2 meters thick, were traced for more than 20 km along strike. They were deposited with upper Sinian beds of shales and slates. The upper bed is low in Mn and the two lower ones contained 17-32% Mn in units 0.5-1.5 m. thick. Ores are psilomelane and pyrolusite with minor manganite, rhodochrosite, sericite, calcite, quartz, pyrite hematite and limonite. Compositionally the ores also contain 16-18% Fe, 10-26% SiO_2, 2-4% CaO and about .08% Phos. Reserves are large. The Wafangtzu district is located along the Sinian Trend within which other Mn occurrences are known. The district is one of China's principal manganese producers.	1 (p. 322) 3 (p. 228) 6 (p. 428)

( ) = Pinyin Romanization Spellings

Table A-25 (cont'd).

Name Area–Province	District	Chem. Constituents–% Mn	 SiO$_2$	 P	 Fe	Mining Characteristics	Persistence Characteristics	Remarks	Ref.
	2) Lingyuan	10				Bedded deposit; two Mn beds of 0.1-0.3 m and 0.4 m. thickness; two beds are stratigraphically 10 meters apart.	Overall length of known outcrops are 17 kms.	2) The *Lingyuan* district is located about 150 kms west of Chin Chou near the frontier of Hopeh Province. The occurrence is described as two manganiferous beds within gray-green slates of the Sinian formation, which are separated from each other 10 meters stratigraphically. The upper bed has a reported thickness of 0.1-0.3 m. and the lower a 0.4 m thickness. The average grades are 10% Mn with the upper bed being slightly higher than the lower. Reserves are "medium" (from 1-10 MMT).	1 (p. 323) 3 (p. 227)
	3) Fengcheng	28				–	Ores in slates and dolomites.	3) *Fengcheng* district 150 km south-southeast of Shenyang includes the Fengcheng and Wulungpei deposits. Pyrolusite and psilomelane are principal minerals in slates and dolomites.	1 (p. 323) 5 (p. 56)
	4) Hsingcheng	45-48					Hydrothermal-metasomatic contact deposits in limestone near igneous intrusive.	4) The *Hsingcheng* district is about 260 km southwest of Shenyang.	1 (p. 323) 5 (p. 56)
	5) Cháo-Yang	*Primary Ore* *(Carbonate)* 15-18 *Primary Ore* *(manganite)* 20-30	 17-23 22-27	 * –	 10-15 12-18	Three ore beds; lower one near the base of the series; the middle bed is 4-6 m above it, and the upper is 8-12 m above the middle one. The upper bed is irregular whereas the middle and lower are more persistent, consisting of small lenses. Ore grades laterally and vertically from carbonate to oxides. Primary oxide and carbonate ores are blocky and massive, oolitic or pisolitic	The manganese ore-bearing sediments in the upper part of the Upper Sinian age Hung-shui-chuang formation, extends intermittently for about 200 km.	5) *Cháo-yang* is located 250 kms WSW of Shen-yang and 75 km north of Chin Chou. The Mn deposits occur at the top of the Upper Sinian Hung-shui-chuang formation. They overlie gray cherty limestones and black shales and are overlain unconformably by Lower Cambrian basal conglomerates. The manganese-bearing series is 20-30 meters thick and is made up of brownish-colored dolomites, gray-brown shales and interbedded silt-stones. The shale contains chert layers.	2 (p. 837)

						in texture. The secondary oxide ore is loosely compacted and contains yellow clay.		There are three Mn layers. The ore grades both laterally and vertically from carbonate to oxide ores. Ores are both primary oxide and carbonate and secondary oxides. Primary oxide ore is manganite, the carbonate ores are manganous calcite and some ferroan rhodochrosite. *The CaO+ MgO content is 8-15%	
Kirin Prov. *(Jilin)*	1) Lishu	23					Ore occurs as pockets and nodules in limestones.	1) The *Lishu* deposit is 80 km southwest of Changchun. Psilomelane is principal mineral.	1 (p. 327)
	2) I-tung	–						2) A second deposit is located at *I-tung* 60 km south of Changtung.	
Heilungkiang *(Heilongjiang)*	1) Tungho	"good quality"						1) *Tungho* deposit is 160 km east of Harbin. Manganite is the principal ore mineral.	1 (p. 329)
								2) Manganese also reported in the Great Hingan Range in the northeastern part of the province.	1 (p. 329)
NORTHWEST CHINA Shensi Prov. *(Shaanxi)*								Shensi: No significant Mn deposits.	1 (p. 330)
Kansu Prov. *(Jansu)*	1) Yungteng	41.5	2.71	nil	nil		Bedded deposits.	1) The *Yungteng* district is located 90 km northwest of Lanchou, and the main deposits are at Lanmenshih and Hsiwan. Analyses show 0.21% Pb, 0.65% Ag and negligible S. Principal minerals are pyrolusite and psilomelane. Reserves are small–less than 1.0 MMT.	1 (p. 332)
	2) Chingyuan	44.9						2) The *Chingyuan* manganese district is 100 km northeast of Lanchou. The one known deposit is at Heishihshan and the principal mineral is pyrolusite. Grade reported as 71% MnO_2.	1 (p. 332)

Table A-25 (cont'd).

Name Area–Province	District	Chem. Constituents–% Mn	 SiO_2	 P	 Fe	Mining Characteristics	Persistence Characteristics	Remarks	Ref.
Tsinghai *(Qinghai)*	Chi-lien-shan	20-30	"high"	–	–	Orebodies are lenticular, several hundred meters long and 3-10 m thick. Occur in calcareous metamorphosed volcanic rocks.	Lenticular orebodies are several hundred meters long and occur in an ore-bearing belt more than 1 km long.	The manganese ore deposits of the Chi-lien-shan syncline are associated with highly calcareous metamorphosed volcanic rocks in the upper part of the Devonian Pai-yin-chang member. The rocks above and below the ore beds consist of andesite porphyries, cherts, siliceous phyllites and manganese-bearing limestones. The ore is high in silica and, in places, consists of manganese-bearing chert. The ore minerals are pyrolusite, psilomelane with small amounts of magnetite and goethite. Based on the geologic occurrence, the ore deposit is a marginal deposit of the syncline. The source of the Mn and silica is attributed to submarine volcanic activity.	1 (p. 333) 2 (p. 837)
Sinkiang-Uighur Autonomous Region *(Xinjiang-Uygur-Zizhiqu)*	1) Turfan	–	n.a.	–	–			1) Manganese deposits reported in the Turfan depression.	1 (p. 337)
Inner Mongolian Autonomous Region *(Nei Mongol Zizhiqu)*	1) Fengchen	–	n.a.	–	–			1) The *Fengchen* manganese deposit is located about 260 km west of Peking. The ore contains galena.	1 (p. 338)
EAST CHINA Shantung *(Shandong)*	1) Laoshan	n.a.	–	–	–			1) The *Laoshan* manganese district, 20 km north of the port of Tsingtao, includes Taochuapo, Chinshui, Laokuanwu which as a source of ferromanganese ores have been mined for years.	1 (p. 342)
Kiangsu *(Jiangsu)*	1) Tunghai County	30-60				Associated with limestones and gneisses.		1) The Haichou manganese district (principal deposit is Chinpingshan) is located in *Tunghai* County close to the border with Shantung Prov.	1 (p. 343)

	2) Wushi	n.a.					2) *Wushi* is located 150 km S-Se of Nanking in southeastern part of province.	1 (p. 343)
Anhwei *(Anhui)*	1) Hsuancheng	n.a.				Marine sedimentary type	1) *Hsuancheng* district is located about 170 km southeast of Hofei, the capital city. Reserves are less than 1 million metric tons. Deposits are Permian Age.	1 (p. 344)
Chekiang *(Zhejiang)*	1) Hangchou	n.a.				Ore associated with limestones and quartzites.	1) The *Hangchou* manganese district is situated around the provincial capital at Hangchou in the northern part of the province. It includes the Hangchou, Yuhang and other deposits. The ores are psilomelane, pyrolusite and some manganite.	1 (p. 345)
	2) Wulungchen	49.75	–	–	12.64		2) The *Wulungchen* manganese district is 90 km west of Hangchou. Analyses, dated 1930, reported: MgO 8.02%, CaO 0.54%, S 30.15% (Note: the S 30.15% may be in error).	1 (p. 345)
	3) I-wu	n.a.					3) The *I-wu* district is located 100 km south of Hangchou. Psilomelane is the principal mineral.	1 (p. 345)
	4) Taishun	n.a.					4) The *Taishun* district is in the southern part of the province near the boundary with Fukien. Main ore mineral is psilomelane.	1 (p. 346)
	5) Other	–					5) *Linhai*, 170 km SE of Hangchou Hsinchang, 110 km SE of Hangchou Chuchi, 65 km south of Hangchou Loching, 160 km NE of Taishun Pingyan, 80 km east of Taishun	1 (p. 346)

Table A-25 (cont'd).

Name Area–Province	District	Chem. Constituents–% Mn	 SiO_2	 P	 Fe	Mining Characteristics	Persistence Characteristics	Remarks	Ref.
Fukien Province *(Fujian)*								Manganese deposits located chiefly in the southern part of the Province.	1 (p. 350)
	1) Fuching	–						1) *Fuching*, 40 km south of Fuchou	
	2) Putien	38.35	–	–	–			2) *Putien*, 50 km SW of Fuching	
	3) Lungyen	–						3) *Lungyen*, 260 km SW of Fuchow	
	4) Wuping	–						4) *Wuping*, 90 km west of Lungyen, on border of Fukien and Kiangsi.	
	5) Yenchien	"high grade"					Residual deposits	5) *Yenchien*, 30 km SW of Wuping.	
CENTRAL SOUTHERN CHINA Kiangsi Province *(Jiangki)*	1) Loping	44-51				Several beds up to 20 meters thick.	Marine sedimentary type	1) Loping** district in northeastern part of province is 120 km ENE of Nanchang, includes: Tatiehling, Hsiaotiehling, Wangchiashan near Chungfou (20 km SE of Loping). Deposits are of marine sedimentary type associated with sandstones and pelitic sandstones. Psilomelane is principal ore mineral. District reserves are less than 1.0 MMT. Deposits are of Middle Carboniferous age. Upper Permian marine sedimentary type of Mn deposits have been found in Western Kiangsi Prov. Chao (Ref. 2) reports a 1955 discovery of Mn carbonates in N.E. Kiangsi with residual oxides. There were 4 Mn seams of 0.3-0.6 m. thickness in a 10 m. thick zone. The carbonate protore ore contains 15-25% Mn, 13% SiO_2, 12-14% CaO and 25% LOI. **(Leping on Provincial Map)	1 (p. 352) 2 (p. 840)
Honan Province	No manganese deposits reported.								
Hupeh Province *(Henan)*	1) Tayeh Dist.						Bedded manganiferous limonite	1) *Tayeh* dist. in southern part of Prov. Paiyanglin is principal deposit consists of bedded manganiferous limonite. Yanghsin deposit contains psilomelane and manganite. Pre-Sinian metasedimentary type deposits found in northern Hupeh.	1 (p. 356)

Hunan Province *(Hunan)*	carbonate ore* Hsiang-t'an	11-25	17	–	–	The Hsiang-t'an manganese deposits, along with the Chihsien deposits in Hopeh and the Cháo yang deposits in Liaoning, are a part of the Sinian age formations which extend intermittently for a strike length of 200 kms.	The Hsiang-t'an manganese district is located in the eastern part of the Prov., about 30 kms south of Chiang-sha. The principal areas have been identified as: Yenchiachung, Hsiaochiawan, Fushanfeng, Tachungwan (Shangwutu) and others. The manganese deposits are sedimentary and are associated with the Hung-Chiang series of Lower Sinian age. They unconformably overlie the Proterozoic Panchi series of regionally metamorphosed greenish-gray siliceous and clayey shales and are unconformably overlain by the Lower Sinian age Nan-túo tillites. The Hung-chiang series consists of dark to medium gray sandstones intercalated with lenses of limestone in the lower part and black to gray siliceous and carbonaceous shales with disseminations of pyrite and thin beds of manganese ore in the upper part. The main ore-bearing bed occurs at the lower part of the ore-bearing section and consists of black manganese carbonate. Those beds within 40-50 m of the surface and under the water table were converted to oxidized ore. Ikonnikov (p. 359) classifies the reserves of over 10 million tons of 40-50% Mn oxide ores. One of the principal Mn producers in China. *Additional analyses of carbonate ore are CaO+MgO – 9%; LOI 20-30%.	1 (p. 359) 2 (p. 837) 6 (p. 428)
	Chung Shui	45-55				Deposits are of marine sedimentary type.	*Chung Shui* district is located in the Chung Shui river valley (formerly the Chungling Shui) about 160 km south of Hsiangtan. Ore deposits are of marine sedimentary type of early Sinian age. Ore consists of psilomelane, manganite and secondary pyrolusite. Reserves are 1-10 MMT.	1 (p. 359)

Table A-25 (cont'd).

Name Area–Province	District	Chem. Constituents–% Mn	SiO$_2$	P	Fe	Mining Characteristics	Persistence Characteristics	Remarks	Ref.
	Other Deposits	n.a.						Minor Deposits at: *Yushien*, 135 km SSE of Changsha *Anjen*, 30 km S of Yushien *Yunghsing*, 65 km S of Anjen *Chenchou*, 40 km S of Yunghsing *Jucheng*, 80 km SE of Yunghsing *Hengyang*, 70 km W of Anjeng *Liling*, 80 km SE of Changsha *Yuehyang*, 140 km N of Changsha	1 (p. 360)
Kwangtung Province *(Guangdong)*	1) Huachou	"low grade"					Residual characteristics.	1) *Huachou* district (formerly the Huahsien district) is 320 km SW of Canton and includes the Tatunpu, Fengchiling and other deposits. Ore contains pyrite and some cobalt. The deposits are residual and the reserves are small.	1 (p. 363)
	2) Other							2) Other deposits are at: a) *Fengkai* (Chiangkou) 80 km N of Loting b) *Paoan* (Shenchuan) 110 km SE of Canton c) *Lienchiang* 40 km W of Huachou d) *Huahsien* 40 km N of Canton	
Kwangsi-Chuang Autonomous Region *(Guangxi-Xhuangzu Zizhiqu)*	I-Shan	n.a.					Marine sedimentary deposits	*I-Shan* district located in northern part of region, 190 km north of Nanning. Marine sediments of Early Carboniferous age; major ore minerals are manganocalcite and rhodochrosite. Reserves are large, i.e. more than 10 MMT.	1 (p. 367)
	Laipin	n.a.					Marine sedimentary deposits	*Laipin* district is located in the central part of the region, 140 km northeast of Nanning. Marine sedimentary deposits of Late Permian age. Deposits contain ferromanganese ores often with cobalt and nickel. Reserves are large, i.e. excess of 10 MMT.	1 (p. 367)

Kueiping	47%	Residual deposits	The *Kueiping* district (Mukuei) is in the SE part of the region, 185 km NE of Nanning. Reserves are classified as large, i.e. greater than 10 MMT. Principally residual deposits containing psilomelane. Mukuei is one of China's principal producers.	1 (p. 367) 6 (p. 428)
Lingshan	n.a.	Residual deposits	*Lingshan* district in southern part of the region, 110 km ESE of Nanning. Residual deposits with psilomelane, pyrolusite and manganite. Usually contain some cobalt. Reserves estimated to be 20 MMT.	1 (p. 368)
Fangcheng	n.a.	Marine sedimentary	*Fangcheng* district is 125 km SW of Lingshang. Ores of marine sedimentary types of Late Permian age. Contain psilomelane and pyrolusite. Reserves are listed at 1-10 MMT.	1 (p. 368)
Pupei	n.a..	Marine sedimentary	*Pupei* manganese district is located about 30 km SE of Lingshan. Deposits are Late Permian marine sedimentary. Reserves less than 1 MMT.	1 (p. 368)
Sanmenchiang	n.a.	Marine sedimentary (?)	*Sanmenchiang* (Sanchiang) is located 120 km NE of Laipin. Deposits are Late Permian (marine sed ?). Reserves are less than 1 MMT.	1 (p. 368)
Shihlung	n.a.	Marine sedimentary (?)	*Shihlung* district is 35 km NE of Laipin; similar to Laipin deposits. Reserves less than 1 MMT.	1 (p. 369)
Tungping	-	Bedded manganese oxides; sedimentary. Ore beds reported to occupy a 35 sq. km area.	*Tungping* located in southern Kwengsi-Chuang (exact location not known); bedded sedimentary deposits of Late Permian age. Reserves estimated at 15 MMT.	1 (p. 369)

Table A-25 (cont'd).

Name Area–Province	District	Chem. Constituents–% Mn	SiO_2	P	Fe	Mining Characteristics	Persistence Characteristics	Remarks	Ref.
	Yao-shan	*Basal Ore Bed* 35-40	15-19	P	6-7	Ores are bedded-stratigraphic units associated with platy sandy shales interbedded with layers of black chert and black manganese-bearing limestones. Basal ore bed thickness of from 0.5-10 meters.	Stratigraphic deposits enriched in near surface zones from extensive weathering and oxidation.	The deposits occur on the slope of Yao-Shan. The ore occurs in two stratigraphic horizons within the Liu-chiang series of Upper Devonian: 1) One ore horizon occurs in the basal part of the Lieu-chiang series above the erosional surface separating it from the underlying Middle Devonian Tung-kang-ling limestone. The ore is bedded. 2) The other horizon consists of several seams of manganese ore occurring in the middle of the Lieu-Chiang series. Of these, the top most one is the most persistent whereas the others are more lenticular. The strata above and below the ore-bearing horizons consist of purple-brown platy sandy shales interbedded with layers of black cherty and some manganese-bearing limestones. The ore consists of soft manganese oxides occurring in botryoidal or boxwork types of structure. The manganese minerals are usually psilomelane and pyrolusite. The thickness of the ore in the basal part of the Liu-chiang series is from 0.5-10 meters. The ore in the middle part of the series is of poorer quality. The formation of this ore was from the oxidation of manganese-bearing rocks occurring near the surface.	2 (p. 837)
		Middle Ore Bed 20	30	–	9				
	Other	n.a.						Other: a) Chinhsien, 35 km NE of Fangchen and Wuhsuan. b) Wuhsuan, 45 km N of Kueiping.	1 (p. 369)

SOUTHWEST CHINA					
Szechwan Prov. *(Sichuan)*	Changning	–		*Changning* district (only one reported in Szechwan) is located in the southern part of the province, 280 km SSE of Chengtu.	1 (p. 372)
Kweichow Prov. *(Guizhou)*	General (See Remarks)			The manganese deposits of *central Kweichow* are associated with marine rocks of Permian age. The manganese ore formation is at the unconformity between the top of the lower Permian Pai-ni-t'ang formation and the base of the upper Permian Loping coal series. The Pai-ni-t'ang formation consists of pyritiferous gray-black siliceous limestones which overlie the Yang-hsin limestones. The orebodies are in the dark gray-black shales which underlie the coal series. The ores average 2 meters in thickness and are persistent laterally. The beds above and below the ore contain crystals and concretions of pyrite. Surface ores, developed under the present weathering cycle, consist of pyrolusite and psilomelane in botryoidal forms and in boxworks filled with powdery ores. These ores contain 10-30% Mn, 8-20% SiO_2, and 5-20% Fe. The ores below the oxidized zone at depths of 20-30 meters consist of manganoan calcite with rhodochrosite bearing light gray carbonate rocks. This ore contains 17-23% Mn and 5-12% CaO. Primary sedimentary pyrite crystals are also reported.	2 (p. 842)
	Tsun-i	n.a.	All deposits are bedded and usually have three beds with thicknesses of 7-8 meters each.	*Tsun-i* district is located about 120 km north of Kueiyang. Marine type sediments of Late Permian age; ferromanganese ores with cobalt and nickel. Reserves are estimated to be "tens of millions of tons", thus making them the largest in the country. One of China's principal manganese producers.	1 (p. 375) 6 (p. 428)

Table A-25 (cont'd).

Name		Chem. Constituents–%							
Area–Province	District	Mn	SiO_2	P	Fe	Mining Characteristics	Persistence Characteristics	Remarks	Ref.
	Weining	n.a.						*Weining* located in the wester part of the province has reported manganese deposits.	1 (p. 376)
Yunan Prov. *(Yunnan)*	Tungchuan	n.a.						*Tungchuan* located 120 km NNE of Kunming. Marine triassic.	1 (p. 378)
	Hsuntien	n.a.						*Hsuntien* located 85 km NE of Kunming.	1 (p. 378)
	Lopeing	n.a.						*Lopeing* located 165 km E. of Kunming.	1 (p. 378)
	Anning	n.a.						*Anning* located 25 km SW of Kunming.	1 (p. 378)
	I-men	n.a.						*I-men* located 70 km SW of Kuming..	1 (p. 378)
Autonomous Region of Tibet *(Xizang Zizhiqu)*	Tanglha Range	n.a.						*Tanglha Range*, along the Tibet-Tsinghai frontier contains reported manganese occurrences.	1 (p. 383)

*See Remarks

REFERENCES

Argall, G.O., Jr., Mining Operations and Mineral Deposits of China, World Mining 32,p. 68, October 1979.

Chia-hsiang, C. and You-hsin, L., Preliminary Study of the Manganese Deposits of China, International Geological Review, AGI 2, p. 833, 1969.

China's Mineral Industry, Canadian Mining Journal 94, p. 21, January 1973.

DeHuff, G.L., and Jones, T.S., Manganese, Mineral Commodity Profile, U. S. Bureau of Mines, Washington, D. C. 1979.

Ikonnikov, A.B., Mineral Resources of China, Microfilm Publication No. 2., Geological Survey of America, Boulder, CO., 1975.

Muraoka, M., Manganese Deposits in Manchuria, Symposium on Manganese Vol. IV, 20th International Geological Congress, Mexico, 1956.

Oiwa, Y., Nordquist, C.G., and Lentz, O.H., The Mineral Industries of Japan and Southeast Asia, Quarterly of the Colorado School of Mines, 56/4, October 1961.

U.S. Bureau of Mines, Economics and Statistics Division, Mineral Resources of China 2/7, January 1948.

U.S. Bureau of Mines, Minerals Yearbooks, U. S. Government Printing Office, Washington, D. C., various years.

Wang, K.P., China, Mining Annual Review, p. 428, June 1979.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books, Ltd., Garden City Press, Ltd., Hertfordshire, U. K., 1977.

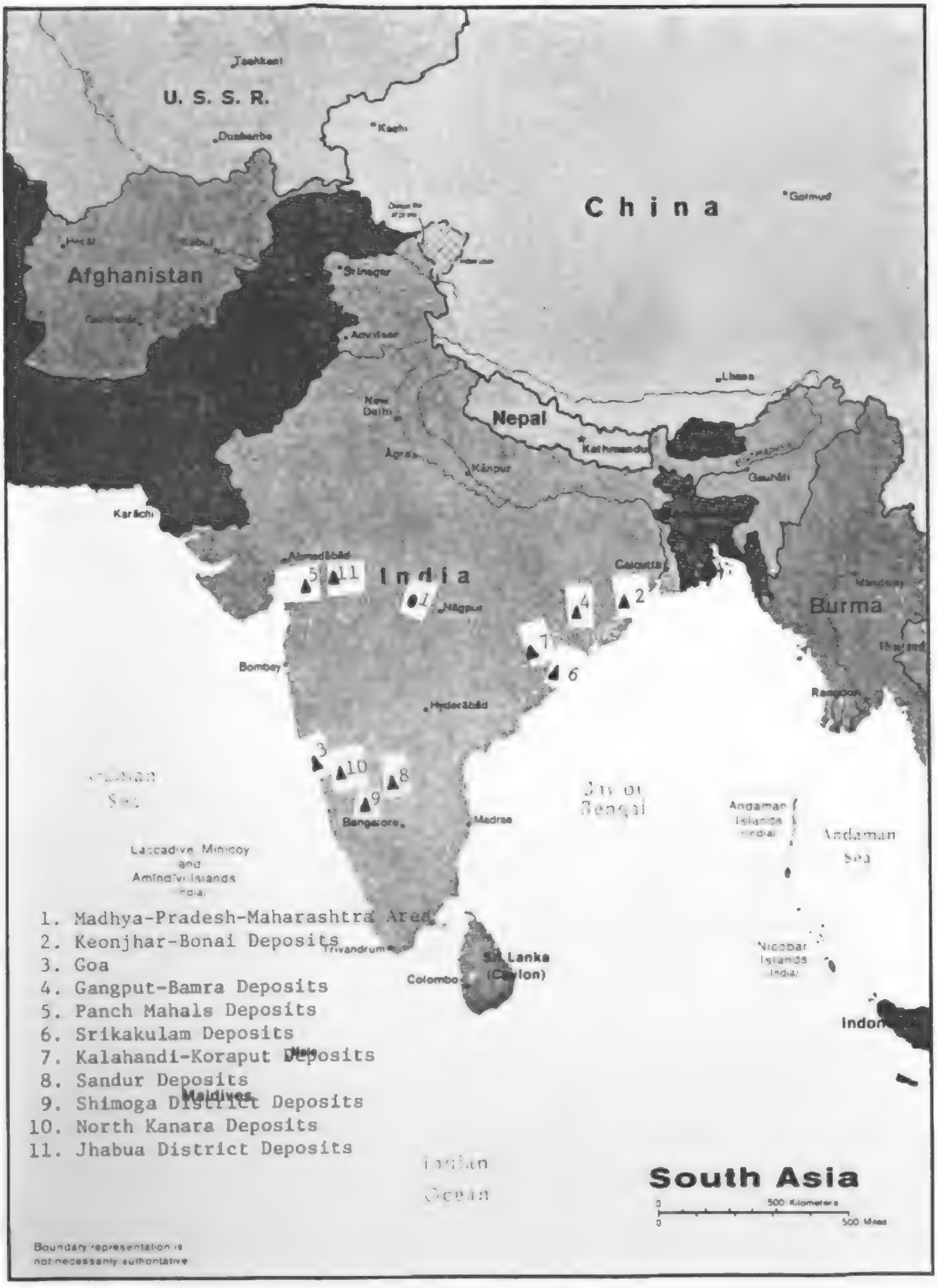


FIGURE A-10. Manganese Deposits in India and Goa

A.15 INDIA

Commercial mining of manganese ore started in India in 1892. The total production, from the beginning of operations until the end of 1978, can be estimated at some 77 to 82 million m.t. (including manganese ore produced in Goa). The yearly output increased irregularly from 675 m.t. in 1892 to slightly over 1 million m.t. around 1926 and stayed at that level until 1929. From then until 1950, it strongly oscillated between 200 thousand and 1 million m.t. The peak year of production was in 1953, with over 2 million m.t. Since then the yearly output has been between 1.2 and 1.9 million m.t. It was about 1.83, 1.86, and 1.57 million m.t., respectively, for the years 1976, 1977, and 1978. The yearly average production over the period 1892 to 1978 is 880,000 to 940,000 m.t.

For many years India ranked number two among the manganese-ore producing countries of the world, being largely overshadowed by the USSR. Although its yearly output since the last two decades has been maintained at more or less the same level, the quality of the ore has deteriorated significantly. As a consequence, India has lost much of its importance as a world producer. At present it ranks number six after the USSR, South Africa, Australia, Gabon, and Brazil, which produce more and better grade ores and concentrates.

Indeed, during the long period from 1892 to the present, the overall grade of the ore produced has gradually declined. Until 1950 the grade was still 47 to 52% manganese; then successively 40% or more, 35% or more, and finally an increasing quantity of low-grade ferruginous ore, at less than 35% manganese has been part of the production. In 1973, for instance, 64% of the output graded below 35% manganese and by now this output figure may well have increased.

Considering the great number of manganese deposits all over the Indian peninsula, it is not astonishing that, for example, in 1967 there were 550 registered mines in the country. Thirty of these accounted for 60% of the production. At present there may be some 300 mines, of which only 20 are major operations. Most of these are in Madhya Pradesh. As an example of state production, in 1972 Orissa supplied 31.2% of the total output; Mysore 25.5%; Madhya Pradesh 13.7%; Maharashtra 11.3%; Andhra Pradesh 8.9%; Goa 6.8%; and Bihar 2.6%.

A.15.1 Exports--Local Consumption

Until the early 1970's, the manganese ore industry of India primarily has been export oriented. The peak year of export was in 1957, with 1.75 million m.t. or almost 95% of that year's production. Examples of export figures for other years are as follows: 1 million m.t. or 75% in 1961; 1.2 million m.t. or 81% in 1969; 1.59 million m.t. or 96% in 1970; 862,000 m.t. or 52% in 1972; and 712,000 m.t. or 45% in 1975.

During these years the United States' share of India's export of manganese ore and concentrates has drastically declined, from 44% in 1961 to 6.6% in 1967 to 1.3% in 1970, and practically zero since then. At the same time, Japan's share has strongly increased (40% in 1963, 59% in 1966, and 84% in 1971), so that since the last decade the bulk of the export, primarily a ferruginous-manganese ore, has gone to that country.

In the late 1960's to early 1970's, India started to experience great difficulties as a manganese-ore producer. High mining costs, long transportation distances, and inadequate handling facilities, coupled with deteriorating quality of the ore produced and depletion of reserves, made it impossible to compete with countries like Australia, Gabon, and South Africa. Moreover, high-grade ore, even for domestic use, was in short supply and in 1972 had to be imported from Ghana. As a consequence, in 1974 India banned the export of ore containing more than 46% manganese (except for existing commitments), while export of other varieties of ore was progressively but strongly reduced in order to conserve ores to meet growing domestic demand. During the fiscal year 1974 to 1975, export of ores with 35 to 45% manganese were to be held to 60% of the 1971 to 1972 level. These restrictions have continued. During the fiscal year 1976, the Indian government permitted the government-owned Minerals and Metals Trading Corp. to export to Japan 700,000 m.t. of manganese ore, 60,000 m.t. of "medium-grade" ore (38% manganese), and 640,000 m.t. of low-grade ferruginous ore (Weiss, 1977).

In the meantime, the local consumption of manganese ore in India increased constantly from 600,000 m.t. in 1966 to 790,000 m.t. in 1972. It was 749,000 in 1973 which was comprised of 345,000 m.t. for ferromanganese production, 390,000 m.t. for iron and steel, 12,000 m.t. for batteries, and 2,000 m.t. for other purposes. We may well expect that this increasing trend will continue however, and the role of India as a major exporter of manganese ore will be finished.

A.15.2 Chemistry

Several types of ore are produced, but are characterized by relatively high iron and phosphorus contents. Typical analyses from the three producing areas are shown in Table A-26.

TABLE A-26. TYPICAL ANALYSES OF INDIAN ORES (%)

	Mn	Fe	$SiO_2 + Al_2O_3$	P
Madhya Pradeshi Maharashtra				
Standard perioxide	58.50	2.75	2.00	0.32
Dongri ore	51.00	6.50	4.00	0.30
Oriental mixture	49.25	7.50	15.00	0.15
Other high-grade	46-48	9.00	15.00	0.15-0.20
Medium grade - I	44-46	12.00	15.00	0.15-0.18
Medium grade - II	38-40	12.14	15.00	0.15-0.18
Mysore				
High-grade	46-48	10	14.00	0.10
Medium-grade	44-46	10-12	15.00	0.10
Low-grade	38-40	18-20	16.00	0.10
	30	16-17	15.00	0.08
Orissa/Bihar				
High-grade	46-48	9-10	12.00	0.10
Medium-grade	44-46	9-10	12.00	0.10-0.12
Low-grade	38-40	15	15.00	0.10-0.15
	30	18-20	15.00	n.a.

SOURCE: Weiss, 1977 n.a. = not analyzed

A.15.3 Ore Persistence Character

Manganese deposits in India are widespread and occur in the Indian Precambrian shield. Their geographical distribution is shown in Figure A-10. They may be subdivided in two main geological types.

- Syngenetic, sedimentary deposits in manganiferous formations which comprise primary, bedded ore. These are in Madhya Pradesh, Maharashtra, Andhra Pradesh, Orissa, Gujurat, and Rajasthan (areas 1 to 5, 7, and 11 in Figure A-10).
- Secondary, supergene, epigenetic deposits. These include the so-called "lateritoid" Mn deposits. They occur in Bihar, Orissa, Goa, and Karnataka (areas 6, and 8 to 10 in Figure A-10).

Transitions between the two types exist because supergene alteration and enrichment have also affected the primary, syngenetic deposits.

A.15.3.1 Syngenetic Manganese Formations and Deposits

Manganese concentrations, ranging from chemically deposited manganese-rich ore beds to chemical detrital deposits of impure manganiferous sediments, have been laid down during the Precambrian period in different areas and in different times. They are part of sedimentary, nonvolcanogenic series, each of which has been involved in a cycle of sedimentation, followed by orogenesis, i.e., folding and metamorphism, often in different, superimposed phases. These events did not happen simultaneously in the various areas, but rather during at least three different, long periods. The Eastern Ghats cycle, involving deposits 5 and 7 (Figure A-10) ended about 1.6 billion years ago. The Aravalli cycle, affecting deposits 3, 4, and 11, took place between about 2 billion and 950 million years ago. Finally, the Satpura cycle, involving deposits 7 and 2, ended 846 to 986 million years ago. The metamorphosed, syngenetic manganiferous formations of India are completely devoid of manganese-sulphide and of manganese-carbonate (apart from some epigenetic rhodochrosite). Apparently the sedimentation took place under strongly oxidizing conditions and resulted in chemical precipitation of low-temperature, tetravalent manganese oxides.

During subsequent orogenesis and metamorphism (ranging from the chlorite to the sillimanite zone) different metamorphic manganese minerals were successively formed. The total primary ore deposits include braunite, bixbyite, hollandite, hausmannite, and vredenburgite. The principal metamorphic manganese mineral is braunite ($3Mn_2O_3.MnSiO_2$) the first mineral formed, and persists from low- to high-grade metamorphism. It is often present in two or three generations. The other minerals were formed more or less successively after the braunite, during conditions of higher metamorphism, from the biotite to the sillimanite zone. Thus, the mineralogical composition of the various primary ores is directly related to the grade of metamorphism, while grain size of the constituent minerals increases with the grade of metamorphism.

The impure manganiferous sediments, comprising chemically precipitated manganese-oxide admixed with clay, silica, etc., were metamorphosed into spessartite-rhodonite-quartz assemblages (gondites). According to original composition and grade of metamorphism, these may also contain manganese-bearing micas, amphiboles, or pyroxenes. Manganese-rich parts resulted in the local formation of Mn oxides such as braunite. The gondites do not constitute ore because the Mn that may represent some 25 to 30% is mainly in silicates and cannot be economically recovered.

Lateral and vertical variations and gradations exist from primary ore to gondite, or gondite to quartzite. The generally strong folding and faulting, eventual younger intrusions, and later weathering, oxidation, and local manganese enrichment have complicated or more or less obscured the original relationships in many places. At present the primary deposits occur as conformable tabular or lenticular bodies of widely varying dimensions, often strongly folded and steeply dipping. Supergene enrichment of the manganese formations is always present in varying intensity. It produced concentrations of high-valency manganese oxides such as cryptomelane, pyrolusite, psilomelane, and wad.

The Madhya Pradesh-Maharashtra manganese belt (No. 1 on Figure A-10) is the most important manganese area in India, forming a belt about 200 km long by 25 km wide and containing some 200 scattered deposits of varying dimensions. However, the bulk of the production and of the reserves is contained in only 20 deposits. The manganese ore bodies and associated gondites are part of the Precambrian Sausar Group, a sequence of folded, faulted, metamorphosed, miogeosynclinal, argillaceous, arenaceous, calcareous, and manganiferous rocks. The manganiferous formations occur essentially in the so-called Mansar formation in the upper-middle part of the group. They are associated particularly with metamorphosed pelitic sediments in three stratigraphically restricted horizons. These contain concordant beds of oxidic, massive manganese ore, gondites, and quartzites.

The primary bedded ore consists of alternating layers of essentially braunite and quartzite from a few mm to a m thick and represents original alternating layers of chert and sedimentary Mn oxides diluted by sand and clay. Due to the strong formation, the primary ore bodies occur, according to the local conditions, as folded layers or bands (up to many km long), or as discontinuous lenticular bodies. The latter may form ore zones of over 40 km in length. The width of most ore bands is 1 to 18 m, but due to folding may be up to 75 m wide. The length of the individual ore bodies is up to 6 km. In 1956 the ore depth was shown to extend at least 200 m vertically. In view of the tabular shape and great lengths, they may well extend much deeper. Supergene alterations have enriched both primary ore and gondites, but secondary manganese oxides are only of real importance locally.

The largest manganese mine in the belt (and in fact in the whole of India) is the Balaghat mine (formerly known as the Bharweli mine), owned by Manganese Ore India Ltd. (MOIL). It is in a folded layer 2.7 km long, dipping some 50°, 5 to 10 m wide, and up to 45 m in the nose of a fold. There are three ore zones, six mining levels, and a 600-foot shaft. Annual production is about 75,000 m.t. of ore, but around 1975 only 55% of the manganese content was recovered in the concentrates.

Mining in the Madhya Pradesh-Maharashtra manganese belt started in 1899. Over 90% of the production has been from primary ore, which is mainly metallurgical hard ore moderately high in silica and phosphorus. The higher-grade shipping ores contained (in 1956) about 48 to 52% Mn, 3 to 13% SiO_2, 5 to 11% Fe, and 0.07 to 0.30% P. The lower grades were reported to contain similar percentages of Fe and P, 44 to 48% Mn and up to 20% SiO_2. At present, these figures no longer may be exact.

Most of the ore is mined by open-pit, but important underground workings exist, e.g., at the Balaghat (Bharweli), Gowari Wadhona, Mansar, and Ukwa mines. In 1956 most of the mines were not very mechanized, but this situation has been improved somewhat since then.

According to the available data, the total production of the belt up to 1972 can be estimated at over 32 million m.t., or 45% of the total Indian production. The largest producer has persistently been the Balaghat district (517,000 m.t. in the peak year 1953), followed by the Bhandara district (210,000 m.t. in 1953), the Nagpur district (150,000 m.t. in 1953), and the Chindwara district (38,000 m.t. in 1953).

Results of the most recent detailed ore-reserve estimate available for 1971 are given in Table A-27 reflecting a total of almost 49 million m.t. of reserves (measured, indicated, inferred)for the Madhya Pradesh-Maharashtra district. A 1973 estimate, after exploration drilling was carried out, is 163 million m.t. of total reserves, but details are not available. These are in situ reserves, of which only some 50% can be recovered. Thus, it appears that the area can remain an important producer for many years. It should be noted, however, that these reserves are spread out over a surface of some 500 km^2 and are essentially contained in 20 major deposits. This manganese ore belt accounts for 80% of all the high-grade ore produced in India and contains almost all known reserves of this type of ore.

A.15.3.2 Other Manganese Deposits of the Syngenetic Type

The deposits in the Jhabua district, Madhya Pradesh (No. 4, Figure A-10) in the Panch Mahal and Baroda districts, Gujarat (No. 3), and in the Banswara district, Rajasthan (No. 11), all occur in the so-called Aravalli Group (or in the equivalent Champaner Group) of Precambrian sediments.

TABLE A-27. DISTRIBUTION OF MANGANESE ORE RESERVES IN INDIA (January 1, 1971)

	MEASURED (million m.t.)					OTHER (million m.t.)				
	H.G.	M.G.	L.G.	Unclassified*	Total	H.G.	M.G.	L.G.	Unclassified*	Total
Orissa	--	--	--	--	--	--	3.75	6.86	33.03	43.64
Madhya Pradesh & Maharashtra	7.03	0.12	--	0.06	7.22	36.93	4.51	0.17	0.17	41.78
Mysore	--	0.23	0.06	--	0.29	0.98	1.54	1.02	11.42	14.96
Gujarat	--	--	--	--	--	2.01	0.54	--	0.35	2.90
Andhra Pradesh	--	0.01	0.14	--	0.15	--	0.29	1.26	--	1.55
TOTAL	7.03	0.36	0.20	0.06	7.66	39.92	10.63	9.31	44.97	104.83

H.G. = High-grade: +46% manganese
M.G. = Medium-grade: -46+38% manganese
L.G. = Low-grade: -38% manganese
*Unclassified = Grades are overlapping
-- = No data available

In the Jhabua district only the Kalidongri deposit is of some importance. The grade of the primary ore, occurring in several steeply dipping ore bands over a length of 1 km, is reported as 40 to 45% Mn, 10 to 12% Fe, 9 to 11% SiO_2, and 0.25 to 0.31% P. Between 1902 and the 1960's, about 1 million m.t. of ore have been produced. There are no figures for reserves or resources in the district, but the latter are without a doubt very limited.

In the Panch Mahal and Baroda districts, about 50 bedded manganese occurrences are grouped in three or four different clusters. The individual deposits are up to 2 km long and 17 m wide, and extend to a known depth of 170 m. Supergene alteration and enrichment is intense. A reported analysis of the ore, not necessarily typical, gave 44 to 50% Mn, 3.5 to 6% Fe, 3 to 11% SiO_2, and 0.26% P. The deposits have been worked continuously since 1906 by open-pit and more recently by underground mining. Total production up to 1974 is about 2.6 million m.t. At present the output has dwindled to a few thousand metric tons per year. In 1971 the reserves were estimated at 2.9 million m.t.

In the Banswara district, the deposits extend a length of 20 km and are small and rather low grade. They have been strongly subjected to supergene alteration. Total production since 1940 may be only 75,000 m.t. In 1969 reserves were estimated at 2 million m.t. grading 28 to 48% manganese.

The Gangpur-Bamra deposits in the Sundergarh (Bonai) district in Orissa (No. 2, Figure A-10), occur in highly folded micaschists and phyllites of the Precambrian Gangpur formation, metamorphosed during the Satpur cycle. There are some 20 tabular, strongly discontinuous bodies of manganese ore and gondite measuring up to 350 m long and 7 m thick. Primary manganese ore (mainly braunite) is only present in subordinate amounts. Most workable deposits consist essentially of supergene manganese oxides. The deposits had been worked from 1907 to 1933 and the area no longer appears to be of any importance.

The Kalahandi-Koraput-Patna areas in Orissa and the Srikakulam-Vizagapatam area in Andhra Pradesh (areas 7 and 6, Figure A-10), although separated, are in the same geological series and located in the Eastern Mountains (Eastern Ghats). They are part of the so-called Khondalite Series that stretches over a length of 500 km. The series represents sediments of the Archean age, including manganese formations that have been folded and metamorphosed into the granulite facies.

The Kalahandi-Koraput Manganese belt in Orissa, 32 km long by 2.5 to 3 km wide, comprises over 20 manganese deposits. About 160 km to the north, the Patna area contains 18 deposits scattered in a zone measuring 12 to 16 km. The available description of these deposits dates from 1956 when all workings were still in the supergene zone, so that little is known of the primary bedded deposits. The ore bodies are essentially conformable tabular lenses enclosed in clay and weathered schists, measuring up to 200 m long and 12 m wide. Some deposits are a mixture of quartz and varying amounts of mainly supergene Mn oxides. The ore is of inferior quality, mostly ferruginous, and high in silica and phosphorous. The latest available estimates indicate reserves of 1 million m.t. in the Koraput-Kalahandi area. In the Patna area, the reserves would be 600,000 m.t. at 25 to 34% manganese, 0.22 to 0.53% phosphorus, and high iron values. It appears that the deposits are merely superficial enrichments of low-grade, primary manganese formation and thus they are of very little importance.

In the Vizagapatam-Srikakulam area in Andhra Pradesh, covering 750 km^2, there are about 20 different ore bodies. The primary individual deposits measure up to 700 m long, while the manganese horizons are up to some 10 m thick (locally 50 m due to folding). Most of the ore is supergene enriched, but generally low-grade and high in iron, silica, and phosphorus. Total production between 1892 and 1953 was slightly over 2 million m.t., the maximum output being 136,000 m.t. in 1907. Apparently operations have been resumed in the 1960's and production of 134,000 m.t., 110,000 m.t., and 90,000 m.t. has been reported for the years 1965, 1966, and 1972. In 1971 the total estimated reserves amount to only 1.70 million m.t. (see Table A-27) of mostly low-grade ore.

A.15.3.3 Epigenetic Manganese Deposits

This type of deposit is almost entirely secondary, consisting essentially of the psilomelane-pyrolusite-wad type of manganese oxides that form superficial replacement bodies in Precambrian shales, phyllites, cherts or dolomites, or at the contact between iron formation and phyllite. The ore has apparently been derived from finely dispersed, syngenetic manganese components in certain sedimentary horizons. However, in Mysore (Karnataka), conformable, tabular, or lenticular bodies were found to contain some metamorphic manganese minerals such as braunite. These appear to have been formed from syngenetic, primary sedimentary protore.

The individual deposits are always small, but in certain areas they can be very numerous. Indeed, over 50% of the manganese ore reserves of India appear to be of the supergene type. In general, these ores are only medium- or low-grade.

The "lateritoid Mn ores" of India also belong to the epigenetic type. They invariably accompany and mostly overlie all other types of manganese deposits, i.e., primary bedded ores and secondary replacement bodies, as superficial cavernous manganese ore that resembles laterite. They are always high in iron and often grade into manganiferous iron ore and iron ore. As opposed to most of the syngenetic manganese ores, the phosphorus is generally low. Some of the more important areas containing epigenetic manganese deposits are described below.

The Bonai-Keonjhar-district (Orissa) and Singhbum (Bihar) (No. 6 in Figure A-10) deposits occur in a belt 60 km long and 22 km wide. They are mainly confined to the shales and phyllites of the strongly folded iron ore series, which also includes banded iron formations and large iron ore deposits. There are over 200 deposits from 1 to 300 m long and up to 30 m wide. They are shallow, in general less than 35 m thick. The composition of the ore varies widely from 25 to over 40% manganese, but only 30% of the total reserves are in the latter category. The ore is ferruginous, total manganese and iron generally around 55% and phosphorus varies from 0.085 to 0.120%.

The deposits are worked in a haphazard manner by pits and diggings up to 100 m long, 30 m wide, and 20 m deep. Some more regular quarries are worked by the larger companies like Tisco. Although we have no detailed figures for ore production and reserve estimates, it is likely that the Keonjhar-Bonai belt represents 90% or more of the total production and reserves of the state of Orissa. Since the start of mining until 1974, about 10 to 12 million m.t. of ore have been produced. In the early 1970's, yearly production in the state of Orissa was approximately 450,000 m.t. The total ore reserves in Orissa in 1971 were estimated at 43.6 million m.t., of which only a small fraction is high-grade. Most of these reserves are in the Keonjhar-Bonai belt. In Singhbum, on the northern fringe of this belt, the yearly production is only around 20,000 m.t. Most of the small, scattered deposits have been mined out.

In Karnataka the deposits are very similar, though generally smaller than in Orissa and Bihar. They occur in the Sandur-Bellary, Shimoga, and North Kanara areas (Nos. 8, 9, and 10 in Figure A-10). Most deposits are irregular bodies of lateroid manganese, but some are conformable tabular replacement bodies, extending to depths of over 45 m. These apparently have "roots" of syngenetic, primary protore.

In the Shimoga district the total output since 1906 probably has not been more than a few million metric tons, while the total reserves in 1969 were estimated at 1 million m.t. grading 35 to 45% manganese. In the Sandur-Bellary district, 100 individual deposits are known. They are tabular, bedded bodies below a capping of laterite. They measure up to 300 m long, 120 m wide, and 15 m thick. The total production since 1907 may be 3 to 4 million m.t. In 1969 the reserves were estimated at 800,000 m.t. with 39 to 54% mn, 1 to 5% Fe, and 0.01 to 0.03% p. The reserves of similar deposits in North Kanara were estimated in 1969 at 10 million m.t. with 47 to 54% mn, 5 to 9% Fe, and 0.015 to 0.03% p.

The total annual Mn ore production in Karnataka (Mysore) from all these small, scattered deposits is still relatively important, rising from 140,000 m.t. in 1955 to about 500,000 m.t. in 1972. Total reserves were estimated at 15.25 million m.t. in 1971 (see Table A-27).

A.15.4 Reserves

The reserves of the various manganese ore deposits have been assessed at various times. However, it is still extremely difficult to arrive at any firm figures on the basis of available data. Owing to the lack of adequate exploration by drilling and to the absence of adequate data about the average of the product in various deposits, a large part of the assessments is still based only on surface observations and structural interpretations. The figures given below should be considered with this in mind. One may guess that systematic exploration, which is going on in some areas, may lead to increased reserves in certain cases.

The total proved, indicated, and inferred reserves, as assessed by the Geological Survey of India, have been estimated respectively at some 164 million m.t. in 1965, 182.8 million m.t.in 1967, 112.49 million m.t. in 1971, and 202 million m.t. in 1973. The increase in the most recent figures may well reflect the exploration efforts mentioned above. However, the 202 million m.t. totals mentioned are essentially in the category of inferred reserves. The reserve figures for 1971 as presented in Table A-27 appear to be the most acceptable on the basis of available data.

In the nine years from 1971 to 1979 about 13 million m.t. of manganese ore were produced, representing about 26 million m.t. of crude ore. Therefore, the reserves remaining from the 1971 total are 86.5 million m.t. It is estimated by the panel that as much as 70% of the reserve total may be ferruginous manganese ore.

Although the state of Orissa appears to have the largest reserves, practically all the high-grade reserves are located in the Madhya Pradesh-Maharashtra manganese belt. The only measured, high-grade reserves are in this belt. It should be noted that these figures, as well as most other reserve figures given earlier, refer to in situ ore. If the average ore recovery can be estimated at 50% (taking the Madhya Pradesh belt as an example), the recoverable crude ore reserves of all of India in 1979 would be some 43.25 million m.t.

According to "five-year plans" dating back to the early 1970's, the total requirement of manganese ore for the period 1971 to 1983 would amount to 44.08 million m.t., comprising 13.88 million m.t. of high-grade ore, 8.19 million m.t. of medium-grade, and 22.01 million m.t. of low-grade ore. In comparing these figures with the measured reserve figures of 1971, it is clear that the successful carrying out of the five-year plans is far from sure and that much exploration will have to be done to convert inferred reserves to the measured category. Moreover, important new reserves will have to be located if the manganese mining industry is to grow as predicted without depleting all reserves in less than 20 years.

A.15.5 Goa

Goa, located on the west coast of India, has been a relatively small producer of manganese and ferruginous manganese ores for many years. The yearly production data are now included with that for India; however, Goa's production from 1955 to 1965 averaged about 132,000 m.t. annually.

There are several, relatively small, open-pit mines, including Sanquem, Bicholem, and Quepan, that produce grades varying between 25 and 45% manganese. Production is on the order of 150,000 to 200,000 m.t. per year of ferruginous manganese ore and 20,000 to 30,000 m.t. of manganese ore (W. A. Preston, British Steel Corporation, presentation to the panel, 1979). Typical analyses of the ore are shown in Table A-28.

TABLE A-28. TYPICAL ANALYSES OF MANGANESE ORES FROM GOA (%)

	Mn	Fe	Mn+ Fe	SiO+ Al	P
Medium-grade	38-40	15-16	--	15	0.08
Ferruginous Ore	28-30	18-20	50	15	0.10
Manganiferous iron ore	15-18	28-31	50	16	0.10
Black iron	7-10	42-45	52	12	0.08

SOURCE: Weiss, 1977

The deposits, with pyrolusite, psilomelane, wad, and iron ore, are lateritic ores and occur as widespread, irregular patches of variable dimensions. The deposits are found with iron formation and with quartzite and phyllite of the Precambrian Dharwar system. Development is by pitting and trenching.

The reserves (Roy, 1973) in the working and nonworking mines were calculated by the Indian Bureau of Mines as 10 million m.t. containing 39.07 to 78% manganese. These grades seem to be too high in relation to the ore produced and probably should be 25 to 49% manganese. After deduction of the production since 1973, the reserve would be reduced to about 8.5 million tons. It is presumed that only about 10% of this (850 thousand m.t.) is a manganese ore reserve.

REFERENCES

Roy, B.C., Indian Mineral Resources, Industries and Economics, S. Ghatack from Editions Indian, Calcutta, India, pp. 107-108, 198-200, 1973.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books, Ltd., Garden City Press Ltd., Hertfordshire, U. K., 1977.

BIBLIOGRAPHY

Balasundaram, M.S., Review of the Reserves and Demand Patterns of Iron, Manganese and Chromite Ores in India, The Eastern Metals Review, 25, April 1972.

Brown, J.C. and Dey, A.K., India's Mineral Wealth, Oxford University Press, New York 1955.

Dorr, J.V., Primary Manganese Ores, Anois do 22 Congresso, Soc. Bras. Geol., September 1968.

Dorr, J.V., Manganese, U.S. Geological Survey Professional Paper 809, U. S. Government Printing Office, Washington, D. C., 1972.

Dunn, J.A., Manganese Ore, Revised by S. Narayanaswamy, Bulletin No. 20, Series A, Geol. Suro., India, 1961.

Engineer, B.B., Geology and Economic Aspects of the Manganese Ore Deposits of Jamda-Kaira Valley, Keonjhar and Bonal, Orissa, India, Symposium on Manganese, 20th International Geological Congress, Mexico, 1956.

Hoffman, J.N., Manganese, Its Mineral Deposits and Uses, College of Mineral Industries, Circular No. 49, Pennsylvania State University, 1957.

Karunakaran, C., Manganese Deposits of Mysore, India, Symposium on Manganese, 20th International Geological Congress, Mexico, 1956.

Krishna, Rao, J.S.R., Structure and Stratigraphy of the Manganese Deposits of Vizagapatam and Srikakulam Districts, India, Economic Geology 55, pp. 827-834, 1960.

Krishna, Rao, J.S.R., Microscopic Examination of Manganese Ores of Srikakulam and Vizagapatam Districts, Andhra Pradesh, India, Economic Geology 58, pp. 434-440, 1963.

Krishna, Rao, J.S.R., Association of the Manganese Ores and the Khondalits in Eastern Ghats, India, 22nd International Geological Congress, New Delhi, India, 1964.

Krishna, Rao, J.S.R. and Raju, R.D., Manganese Ores, Andhra Pradesh, India: A Reply, Economic Geology 61, pp. 971-974, 1966.

Krishna, Rao, J.S.R. and Raju, R.D., The Problems of the Nomenclature of the Kodurites, Economic Geology 61, pp. 968-970, 1966.

Lahiri, D., Mineralogy and Genesis of the Manganese Oxides and Silicate Rocks in Kalidjongri Area, Jhabua District, Madhya Pradesh, India, Economic Geology 66, pp. 1176-1185, 1971.

Mahadevon, C. and Krishna, Rao, J.S.R., Genesis of Manganese Ores of Visakhapatnam-Srikakulam District, India, Symposium on Manganese Deposits, Vol. IV, Asia and Oceania, 20th International Geological Congress, Mexico, pp. 63-96, 1956.

Michel, H., Review of the Iron Ore Deposits of India, Internal Report, Geology Department, Bethlehem Steel Corp., 1974.

Mineral Trade Notes, Miscellaneous information on manganese in India from various issues, 1967-1974.

Mining Journal, Annual Review 1974: Far East, 1974

Naganna, C., Origin of the Manganese Ore Deposits of Mysore State, India, Acta Mineralogica-Petrographica XIX/2, 1970.

Prabhakakara, Rao, G., The Geology of the Manganese-Bearing Rocks of Garividl and Garbham, Vizagapatam District, Quat. Journ. G.M.M. Soc. India XXII/2 , 1950.

Prasada Rao and Murty, Y.G.K., Manganese Ore Deposits of Orissa, and Bihar, India, Symposium on Manganese, 20th International Geological Congress, Mexico, 1956.

Rao, G.V., Structural Control and Origin of the Manganese Ore Deposits in the Vizagapatan Manganese Belt, Andhra Pradesh, India, 22nd International Geological Congress, New Delhi, 1964.

Rasul, S.H.. The Manganese Ores of Shivrajpur, District Panch Mahals, Gujarat State, India. Economic Geology 60,pp. 149-162, 1965.

Rasul, S.H. and Khan, M.A., The Geology of the Manganese Ore Deposits of the Taiwara District, Bamswara, Rajasthan, Proceedings of the Indian Academy of Science LVII/3, Section A, 1963.

Roy, B.C., Manganese Ore Deposits of Bombay State, India, Symposium on Manganese, 20th International Geological Congress, Mexico, 1956.

Roy, B.C., The Manganese Deposits of Panch Mahals and Baroda District, Bombay State Bulletin No. 15, Series A. Geological Bureau, Bombay, India, 1958.

Roy, S., Mineralogy and Texture of the Manganese Ore Bodies of Dongarl Buzurg, Bhandera District, Bombay State, India, Economic Geology 54, pp. 1556-1574, 1959.

Roy, S., Study of the Metamorphic Manganese Ores of Bharwell Mine Area, Madhya Pradesh, India, Economic Geology 57, pp. 195-208, 1962.

Roy, S., Mineralogenetic Trend with Regional Metamorphism in the Manganese Ore Deposits of Madhya-Pradesh and Maharashtra, India, 22nd International Geological Congress, New Delhi, 1964.

Roy, S., Manganese Ores, Andhra Pradesh, India, Economic Geology 59, pp. 154-157, 1964.

Roy, S., Genesis of the Manganese Ore Deposits of the Madhya Pradesh and Maharashtra, India, 22nd International Congress, New Delhi, 1964.

Roy, S., Comparative Study of the Metamorphosed Manganese Protores of the World, etc, Economic Geology 60, pp. 1238-1260, 1965.

Roy, S., Syngenetic Manganese Formations of India, Jadaspur University, Calcutta, 1966.

Roy, S., Mineralogy of Different Genetic Types of Manganese Deposits, Economic Geology 63, pp. 760-786, 1968.

Roy, S., Genetic Studies on the Precambrian Manganese Formations of India, Symposium Kiev Earth Sciences, Vol. 9., UNESCO, 1973.

Sondhi, V.P., Manganese Ores in India, Symposium on Manganese, 20th International Geological Congress, Mexico, 1956.

Straezek, J.A., Manganese Ore Deposits of Madhya Pradesh, India, Symposium on Manganese, 20th International Geological Congress, Mexico, 1956.

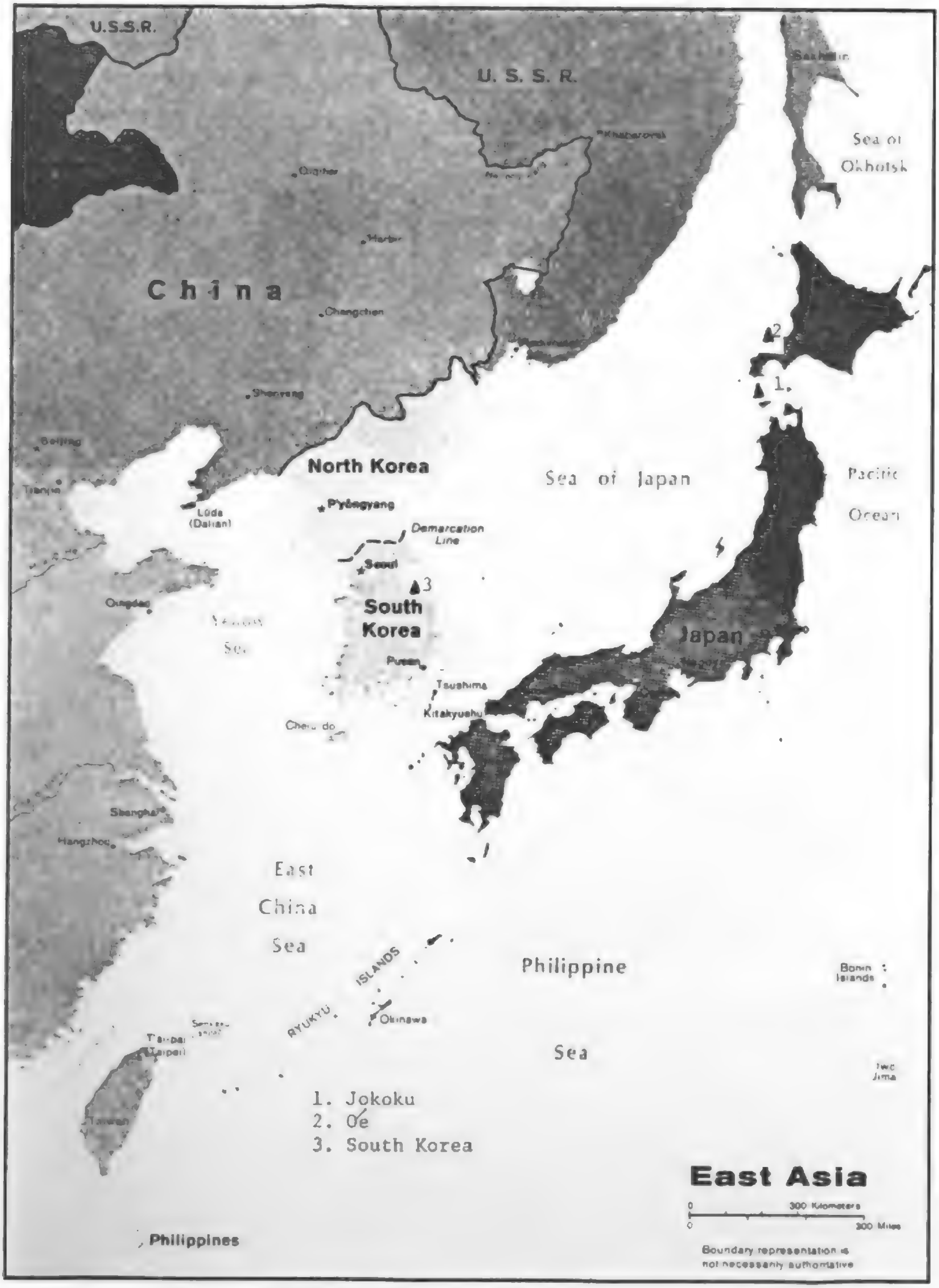
Straezek, J.A. and Krishnaswamy, S., Manganese Ore Deposits of the Vizagapatam District, Andhra, India, Symposium on Manganese, Vol. IV, Asia and Oceania. 20th International Geological Congress, Mexico, pp. 141-158, 1956.

U.S. Bureau of Mines, Minerals Yearbooks, U. S. Government Printing Office, Washington, D. C., 1955-1975.

U.S. Bureau of Mines, Manganese, Materials Survey, U. S. Government Printing Office, Washington, D. C., 1952.

Varentsov, I.M., Sedimentary Manganese Ores, Elsevier Scientific Publishing Company, Amsterdam, Holland 1964.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books Ltd., Garden City Press Ltd., Hertfordshire, U. K., 1977.



1. Jokoku
2. Óe
3. South Korea

FIGURE A-11. Manganese Mines in Japan and Korea

A.16 JAPAN

The production of manganese in Japan has been persistent but relatively small. It reached a peak in 1944 when 400,769 m.t. were produced. After a small decline and a second peak of 348,086 m.t. in 1959, production has slowly declined to 125,038 m.t. in 1977. There are many ore deposits throughout the Japanese islands, but none are very large. In 1958, 239 mines produced 283,483 m.t. of metallurgical manganese ore concentrates, averaging 36% manganese, and 96 mines produced 12,504 m.t. of battery and chemical ores averaging 70% MnO_2.

The manganese deposits of Japan may be classified into several types. Hydrothermal rhodochrosite veins are the most important manganese ore producers. They occur mainly in tuff, tuff breccia, andesite, and rhyolite of Miocene age, especially in southwestern Hokkaido. The deposits are principally composed of rhodochrosite, associated often with alabandite, sphalerite, galena, chalcopyrite, pyrite, and silver minerals. The two largest producing mines located in southwestern Hokkaido are Jokoku and Oe (Weiss, 1977). Each mine produces about 60,800 m.t. of concentrate yearly at a grade of 25 to 30% manganese. The mines produce rhodochrosite ores containing lead and zinc that are beneficiated by flotation, separating the lead and zinc from the manganese. The principal vein of the Jokoku mine has a strike length of 1 km, maximum width of 8 m and a down dip length of 350 m. The Senzai vein of the Oe mine has a strike length of 1.5 km.

Layered and lenticular deposits occur in Paleozoic and Mesozoic formations and are widely found in southern Hokkaido, on the Pacific side of northeast Japan, and in southwest Japan. The deposits are generally small, with small yearly production. Deposits of this type--manganese carbonate and oxide deposits and manganese silicate, carbonate, and oxide deposits--are found in chert, quartzite, graywacke, schists, andesites, basalt, and spilites. The ore is usually composed of rhodochrosite, manganiferous calcite, hausmannite, manganosite, braunite, alleghanyite, bementite, rhodonite, tephroite, and sepssartite. Ratios of constituent minerals are highly variable in individual deposits, but usually carbonate minerals are predominant. The supergene minerals are pyrolusite and psilomelane and often form higher-grade manganese ores that fill fissures and gashes in wall rock. All the deposits are accompanied by thin, residual mineralization.

Small manganiferous hematite deposits are found in Hokkaido, northern Japan, and the outer zone of southern Japan. The deposits have grades of 5 to 10% mn and 30 to 35% Fe.

The 1957 reserves of metallurgical manganese were given as 5.6 million m.t. with an average grade of 27% manganese (larger percentages occur in the Hokkaido vein deposits) and 91,400 m.t. of battery- and chemical-grade ores with 62% manganese dioxide (60 mines) (Geology and Mineral Resources of Japan 1962). In the 20 years since 1957, over 5.3 million tons have been produced. Unless other deposits have been found and brought into production, it is concluded that only small reserves remain.

There is a remote possibility of finding blind vein deposits. The majority of the Japanese manganese deposits are the layered and lenticular deposits. These deposits are generally small in scale, low in grade, and difficult to beneficiate. However, it is presumed that even if more deposits of this type are found, the resource would not be significant. Japan is not listed in the Resources Tables 3-7 or 3-8.

REFERENCES

Geology and Mineral Resources of Japan, Geological Survey of Japan, pp. 194-197, 1962.

Kaneko, K., Manganese of Japan, Symposium on Manganese, Vol. IV, Asia and Oceania, 20th International Geological Congress, Mexico, pp. 173-197, 1956.

U.S. Bureau of Mines, Metals, Minerals, and Fuels, Minerals Yearbook, Vol. I (preprint), U. S. Government Printing Office, Printing Office, Washington, D. C., 1977.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books Ltd., Garden City Press, Ltd., Hertfordshire, U. K., 1977.

A.17 TURKEY

Manganese deposits are reported from a number of localities throughout Turkey. The principal area, which currently produces about 80% of the country's manganese, is in Catalca in northwestern Turkey about 50 km west of Istanbul. References to manganese occurrences in Turkey go back to 1900; however, the maintenance of mineral records of the Turkish Republic did not start until 1925. Production rates have varied over the years, but the rate in 1978 was reported to be 60,000 m.t. Consumption was largely domestic. An expansion to 150,000 tpy by 1980 has been projected (W. A. Preston, British Steel, presentation to the Committee, 1979). Product grades varied from 34 to 38% manganese, with variable SiO_2-Al_2O_3 contents and variable but high sulphur contents. The ore occurs in relatively flat-lying bedded deposits, 0.4 to 1.0 m thick, associated with Eocene sediments consisting of shales and sandstones. Overburden thickness averages 3 m and ranges up to 20 m. Mining is by open-cast and recovery is 100%. The manganese beds appear to be persistent laterally. Reserves are listed as 1 million m.t. measured, 3 million m.t. indicated, and 10 million m.t. inferred. Beneficiation consists of simply crushing and/or screening (Preston, 1979).

A ferruginous manganese deposit having an average grade of 15.5% mn and 24.1% Fe, located at Ceyhan in southeastern Turkey near the Mediterranean port of Iskenderun, has supplied the local steel industry for many years at the rate of several thousand tpy. Reserves are indicated to be substantial and although not quantified could supply 50,000 to 100,000 tpy (Preston, 1979).

BIBLIOGRAPHY

Ryan, C.W., A Guide to the Known Minerals of Turkey, Minerals Research and Exploration Institute of Turkey and the Office of International Economic Cooperation, Ministry of Foreign Affairs, in Cooperation with the U.S. Operations Mission to Turkey, International Cooperation Administration, pp. 114-130, 1957.

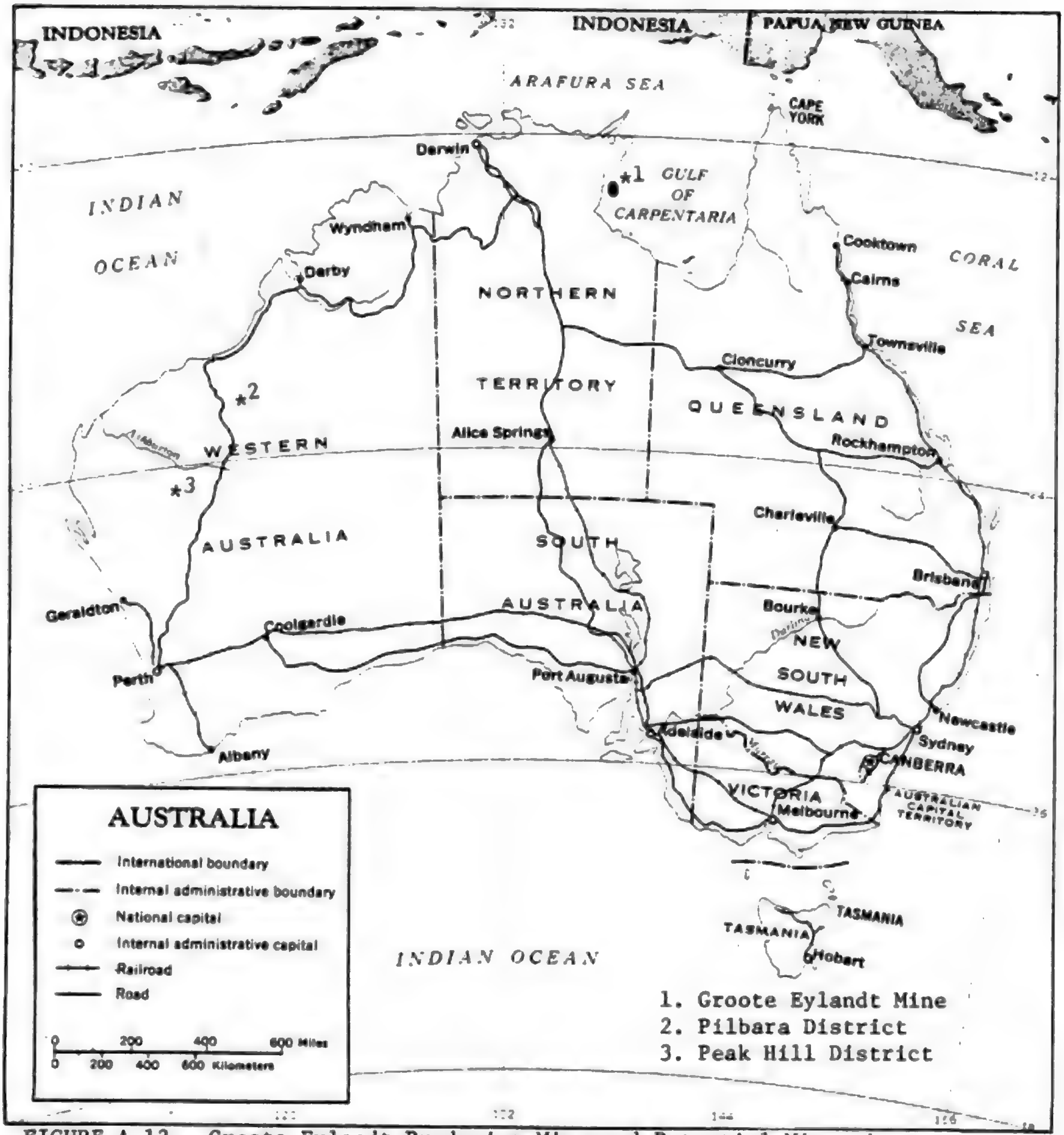


FIGURE A-12. Groote Eylandt Producing Mine and Potential Mines in Western Australia

A.18 AUSTRALIA

Prior to production from the huge manganese ore deposits at Groote Eylandt in 1966, much of Australia's manganese requirements were supplied from small deposits, mainly in western Australia. Other deposits were exploited in past years in Queensland, New South Wales, Victoria, and South Australia. Some small, superficial deposits in the Northern Territory supplied manganese for the uranium ore beneficiation process at Rum Jungle. Another source of supply was a byproduct from the production of zinc concentrates at Broken Hill, New South Wales. Since 1966 Australia's largest manganese production has come from Groote Eylandt in the Northern Territory.

With the exception of the remote Western Australian deposits some 1,100 km from the coast, most of the Australian deposits have been mined out or are too small for any mining activity. Mining of the Western Australia deposits, mostly from deposits in the Peak Hill goldfield and the Pilbara district, occurred mostly during the 1950's and early 1960's. Western Australian reserves were estimated in 1959 at 3.8 million tons of plus 40% manganese ore and 3.2 million tons of 30 to 40% manganese ore (de la Hunty, 1963). Until 1961, 293,000 tons were produced from the Peak Hill deposits and 141,000 tons from Pilbara.

Groote Eylandt, with a current annual capacity of nearly two million tons of product per year, exports most of the product to Japan, Europe, and the United States. Some 180,000 tons per year supply the Broken Hill Proprietary Co., Ltd. (BHP) ferroalloy plant at Bell Bay, Tasmania. In 1977 Australia ranked third in production among the free market countries after South Africa and Gabon, and ranked second after South Africa in manganese reserves and resources (DeHuff and Jones, 1977).

A.18.1 Groote Eylandt, Northern Territory

Groote Eylandt is in the Gulf of Carpentaria about 50 km off the coast of Arnhem Land in the Northern Territory. Manganese was first reported in 1907, but the economic significance of the deposits was not recognized until geologists of the Bureau of Mineral Resources visited the island in 1960, followed by BHP geologists in 1962. A wholly owned subsidiary of BHP, the Groote Eylandt Mining Company Pty. Ltd. (GEMCO), began production in 1966.

The deposits developed as a layer up to 15 m thick in the Lower Cretaceous Mullaman sediments. These are composed of clays, quartz sands, quartzite pebble gravel, and manganiferous marl, in addition to manganese oxide (McIntosh et al., 1975). These beds, dipping gently to the west, unconformably overlie the Middle Proterozoic Groote Eylandt beds consisting of 180 m of cross-bedded sandstone. Lower Proterozoic-Archean gneiss underlies the Groote Eylandt beds.

Manganese ore is known to occur over an area of 150 km^2, mainly on the west side of the island. In the mining area, the ore beds average about 3 m in thickness. Sandstone and clay overburden may be as much as 15 m, but average 3 m. Seven major ore types are described as follows (McIntosh et al., 1975):

1. Pisolitic ore - pisolites and oolites ranging from 1 to 13 mm in a matrix of clay or fine pyrolusite powder. The pisolites are generally formed of alternating shells of cryptomelane and pyrolusite.

2. Cemented pisolites - pisolites cemented in a matrix of laterized sandy clay or manganese oxides. Where manganese oxide cement is pervasive, only the pisolite texture can be seen.

3. Concretionary ore - boulders, cobbles, and pebbles that may have a colloform or faint pisolitic texture.

4. Textureless ore - massive beds of boulders and cobbles with some relict pisolitic texture.

5. Sandy and siliceous ore - boulders, cobbles, and pebbles with disseminated sand grains constituting more than 20% by volume; most commonly found at the base of the ore bed in contact with the Groote Eylandt sandstone.

6. Disseminated ore - alternating layers of pisolitic or textureless ore and sandy clay or clay; also, disseminated pebbles or cobbles of manganese oxide in a clayey matrix that is more than 30% by volume. Generally, this ore is highly laterized (coated with limonitic clay), especially when it is above the main ore bed.

Pilot plant washing tests indicated that the laterized ores occur nearer the surface and are more easily cleaned by scrubbing than the deeper clayey ores (Berry, 1966). Manganiferous marls containing as much as 20% rhodochrosite lie below the manganese oxide bed (McIntosh et al., 1975). The weathering of the marls is the probable source of the manganese oxide that was deposited in the presence of marine foraminifera.

The formation of these deposits in a marine environment appears to have produced a pisolitic type of ore of exceptionally high grade. The pisolites grade 52% manganese or more. Although they are similar in appearance and texture to the pisolites formed in the laterite zone near terrestrial manganese deposits under tropical weathering condition, they contain more manganese and the iron content is only 2%. Pisolites formed in a terrestrial environment seldom grade more than 30% manganese and they contain relatively high amounts of iron, silica, and alumina. The coalescence of these pellets into boulders and cobbles at Groote Eylandt suggests that the manganese ores were subjected to a continual process of mobilization and enrichment of the manganese. McIntosh (1975) states that, The general configuration of the ore body shows that textureless and cemented pisolitic ore types occur near, and west of, the sandstone inliers and along the basin margins but that loose pisolites accumulated in the basins east of the sandstone inliers where gently agitating conditions appear to have existed. The cemented pisolitic ore may have formed by remobilization of manganese during reworking of loose pisolites but evidence of remnant pisolitic texture in textureless ore indicates that these two ore types could have been formed by remobilization of manganese during diagenesis.

The cross sections presented by McIntosh (1975) show that much of the loose pisolitic ore lies below a capping of textureless ore, or that the extension of the loose pisolite layer is now completely occupied by textureless ore. It seems reasonable to conjecture that the pisolites represent original concentrations of the manganese oxides and that have indeed been reworked, but under weathering conditions above sea level. The siliceous pisolitic and concretionary ores near the base of the bed may represent the original manganiferous oxide sediments that, because of their depth, were subjected to less weathering, with attendant mobilization of the manganese and replacement of impurities.

The ultimate origin of the manganese in the sediments is rather speculative, as is true of most major deposits of manganese. McIntosh et al. (1975) demonstrated the marine origin of the deposits at Groote Eylandt by showing that marine foraminifera are present beneath, within, and above the oxide ore bed. As they noted, minor deposits of manganese oxide form thin cappings on dolomites, sandstones, and cherts of the Lower Proterozoic McArthur Group in Northern Australia. The erosion of such low-grade manganiferous rocks may have provided the manganese that was concentrated in the rhodochrosite of the basal manganiferous marl. The marl, under later weathering and erosion, could have been the source of the manganese that was further concentrated as oxides in the shallow sea surrounding the knobs of eroding marl. As conjectured above, additional concentration of the manganese oxides resulted from weathering, perhaps under more humid tropical conditions than those prevailing now.

A.18.1.1 Production and Chemistry

Production began in March 1966 with shipments to the BHP ferroalloy plant at Bell Bay, Tasmania. Early production was at the rate of 200,000 tons per year and by 1976 production had increased to 1.967 million m.t. (Skillings Mining Review, 1977) per year. Total product shipments through 1979 are reported by the company (Rice, 1979) as 13 million m.t. which corresponds to an overall recovery of 47% of the crude ore mined. The metallurgical lump ores grade 49% Mn, 3.3% Fe, 5.8% SiO_2, 3.5% Al_2O_3, 0.09% P, 2.50% K_2O, 0.10% CaO, 0.50% BaO, and 0.20% Na_2O (McIntosh, 1975). Other products include premium natural pellets with 52% Mn, siliceous lump with 43% Mn and 13% SiO_2, high-grade intermediates with 43% Mn, low-grade intermediates with 39% Mn, premium-grade fines with 53% Mn, and low-grade fines with 37% Mn. Rice (1979) states that sinter fines reserves are large and that a new heavy medium expansion will double the production of fines products while at the same time increasing the product grade.

Mining is preceded by stripping of the overburden with open-pan scrapers and separation of the top soil and waste. Following extraction of the ore bed, the waste and top soil are replaced. The ore is blasted and bulldozed into elongate heaps along the length of each mining cut. The broken ore is loaded by rubber-tired, front-end loaders into 32-ton rear dump trucks. In 1973, the average haulage distance to primary crushing facilities was about three kilometers (Berglin et al., 1973).

In 1971, the wet screening plant was replaced with a new plant consisting of two drum scrubbers, two classifiers, and eight cyclones that produce a fines and an intermediate product. Part of the fines product is further cleaned in an 80-ton-per-hour jig section. The plus 12 mm discharge from the scrubbers is cleaned in a ferrosilicon heavy media circuit containing a primary and a secondary drum separator. The primary separator produces high-grade lump product and the secondary separator produces the siliceous lump product. Slimes and minus 0.5 mm tailings are removed in the scrubber circuit and the coarse float product is wasted in the heavy media circuit. The average recovery of lump ore from the crushing and screen plant from 1966 to 1972 was 50.8% and recovery of intermediate product was 22.1% (Berglin et al., 1973). The cleaned manganese ore is hauled 16 km to stockpile areas at Milner Bay. Ship loadings of more than 42,000 tons are possible at the Milner ore loading jetty.

A.18.2 Reserves

No absolute total reserve of manganese ore has been published, although Rice (1979) states that they are at least 300 million m.t. averaging 40% manganese. As noted above, manganese mineralization is reported to extend over an area of 150 km^2 (McIntosh, 1975). In those areas tested by drilling and mining, the ore bed averages three meters in thickness. Without presenting a specific ore area, grade of ore, or recovery factors in the beneficiation process, McIntosh nonetheless estimated reserves of ore as follows:

	Proved	Potential
Massive ore	130 million tons	200 million tons
Loose pisolites	60 million tons	100 million tons

There seems to be no reason to doubt the accuracy of the order of magnitude in this estimate, although there is no indication of grade. Preston (British Steel Corp., personal communication to the panel on September 18, 1979) delineated the ore body to include only that held on GEMCO mining leases, which cover approximately 32 km^2. Using an average thickness of 3 m and a density of 3.3, he calculated a crude reserve of 317 million tons. This he converted to 150 million tons of cleaned metallurgical lump ore running 48% manganese. This may be considered a measured reserve. Preston's figures indicate a weight recovery of 47.3% for the lump product. If the total mineralized area is taken at 150 km^2 and GEMCO's area of 32 km^2 is subtracted, there still appears to be an area of 118 km^2 with substantial potential reserves, if McIntosh's (1975) figure of 150 km^2 is correct.

In lieu of specific exploration data outside the GEMCO area, a conservative approach would be to assume, based on known geologic conditions of considerable interlaying of sandy shales and other materials, that the discontinuous ore beds average 1 m in thickness over an area of 50 km^2. Assuming a density of 3.0 (i.e., lower grade of crude) and a recovery factor of 42% (arbitrarily selected), the yield would be 63 million tons of 48% lump product. This may be considered an inferred reserve.

There may be additional resources in extensions of the ore bed to the west beneath the Gulf of Carpentaria. However, there is insufficient data to assess this potential. For the sake of presenting a complete story, a quantity equivalent to about one-half the total inferred potential of 63 million m.t., or about 32 million m.t., might be added as a hypothetical resource.

In summary, the reserve situation for all of Groote Eylandt is as follows:

Million m.t. of Product at 48% Manganese

Measured	Indicated	Inferred	Hypothetical Resource
150	(See text)	63	32

Although no reserve is included in the "Indicated" category above, it is reasonable to expect that some of the "Inferred" reserve has been adequately demonstrated and should be presented under "Indicated." There are no exploration details available to derive such a number. The contained manganese in the 213 million m.t. of product, shown above as measured and inferred ore, checks well with Rice's (1979) figure after recognizing some recovery losses.

The use of an average thickness of 1 m over an area of 50 km^2 is arbitrary. The further assumption is made that the stripping ratio will be low enough to permit economic exploitation. In this connection, the BHP Pamphlet (1980) states that one of the "factors" determining the location of the three areas of the ore body currently mined "...is...the depth of overburden and nature of the mining conditions, which allow economic mining of the ore resource." This suggests a recognition that in some places the strip ratio may be too high for economic open-pit mining. Material in the high strip ratio areas may add to the above resource figure and reduce the reserve figure correspondingly.

REFERENCES

Anonymous, BHP Groote Eylandt Manganese, Illustrated Brochure of Broken Hill Proprietary Co., Ltd. on the mining operations on Groote Eylandt, (Communicated by BHP.), 1980.

Berglin, C.I.K., McIntosh, J.L., Brunker, C.J., and Freemantle, G.J., Mining and Treatment of Manganese Ores at Groote Eylandt, BHP Technical Bulletin 17/1, April 1973.

Berry, J.E., Pilot Plant Washing Studies of Groote Eylandt Manganese Ore, BHP Technical Bulletin 10/1, 1966.

Blockley, J.G., Pilbara Manganese Province, W.A, Economic Geology of Australia and Papua New Guinea, Monograph 5, Vol. 1. Australasian Institute of Mining and Metallurgy, 1975, Parkville, Victoria, pp. 1019-1020, 1975.

Browne, W.R., The Geology of the Commonwealth of Australia, Vol. II. Edward Arnold and Co., London, U. K., 1950.

DeHuff, G.L. and Jones. T.S., Manganese, Mineral Commodity Profiles, U. S. Bureau of Mines, Washington, D. C., July 1979.

de la Hunty, L.E., The Geology of the Manganese Deposits of Western Australia, Bulletin 116, Survey of Western Australia, Perth, Western Australia, 1963.

Ellis, H.A., Horseshoe Manganese Deposits, Geology of Australian Ore Deposits, Vol. I, Ed. A.B. Edwards, Symposium, Australasian Institute of Mining and Metallurgy, 1953.

McIntosh, J.L., Farag, J.S., and Slee, K.J., Groote Eylandt Manganese Deposits, Economic Geology of Australia and Papua, New Guinea, Monograph 5, Vol. 1, Australasian Institute of Mining and Metallurgy, Parkville, Victoria, 1975.

Rice, P.M., IISI Paper on Manganese, Australian Manganese Ore and Ferro Alloys, unpublished paper dated Oct. 1979, delivered to the IISI Annual Meeting in Sydney, Australia. (Communicated by BHP.)

Skillings Mining Review, 66/22, p. 5, May 28, 1977.

Smith, W.C., Manganese Ore Deposits of Groote Eylandt, BHP Technical Bulletin 9/3, November 1965.

PART II

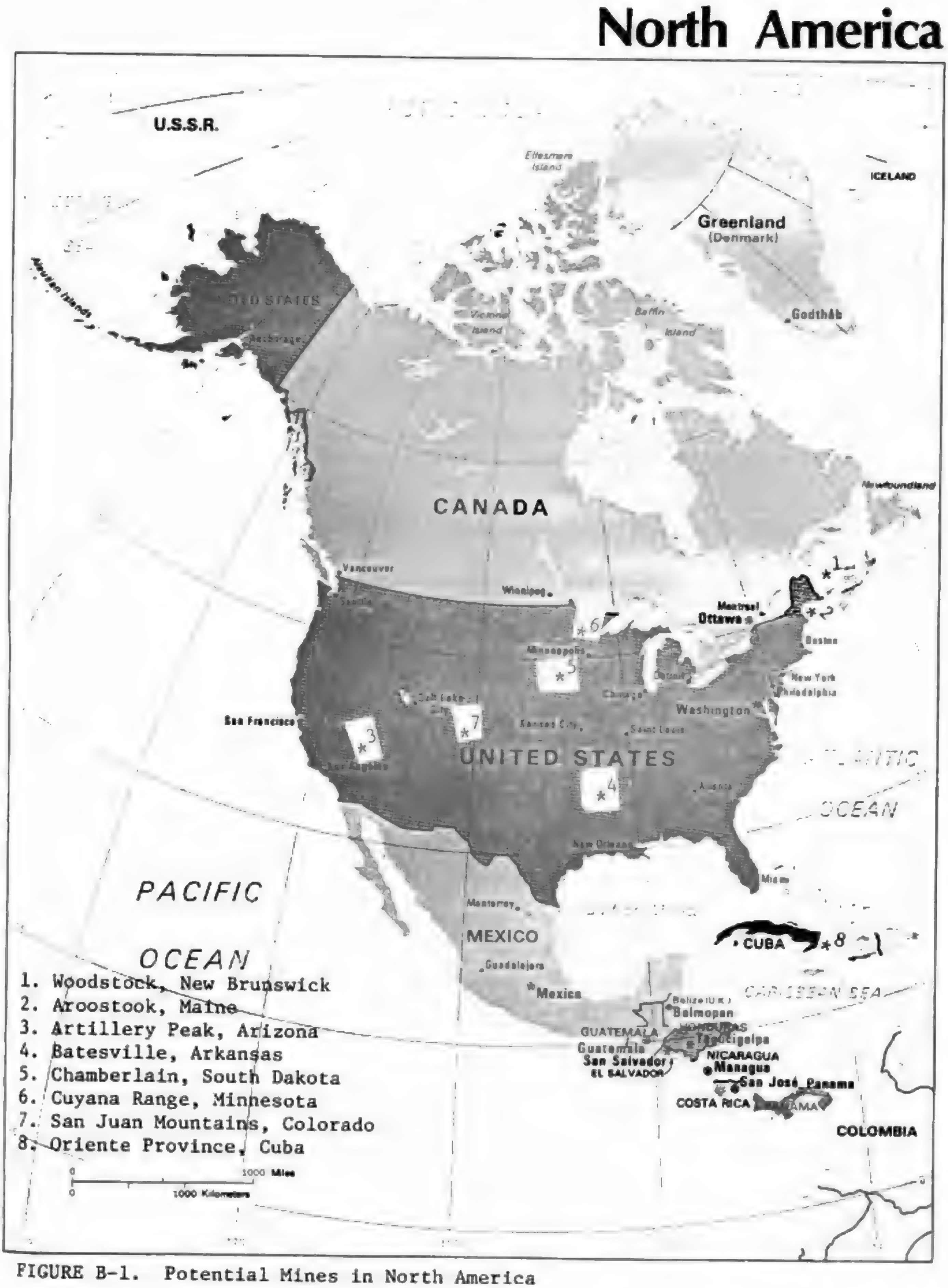
Section B (Minor)

DESCRIPTION OF WORLD OCCURENCES

SECTION B

MINOR SOURCES

This section contains pertinent data on numerous minor sources of manganese, as compiled by the panel. As was done in Section A, the listing is geographically by continent and alphabetical for all countries known to have manganese. The panel has attempted to be as complete as possible, but obviously some omissions may have been made. All in all, the total manganese from all these sources is of significance locally, but does not currently affect the world totals discussed in Section 3.6 of Part I, "Assessment of Major Manganese Reserves and Resource." As was done in Part I, Major Sources, the symbols on the maps describe the type of ore deposit involved in the approximate location: ▲ is a minor producing mine; * is a potential mine.



1. Woodstock, New Brunswick
2. Aroostook, Maine
3. Artillery Peak, Arizona
4. Batesville, Arkansas
5. Chamberlain, South Dakota
6. Cuyana Range, Minnesota
7. San Juan Mountains, Colorado
8. Oriente Province, Cuba

FIGURE B-1. Potential Mines in North America

NORTH AMERICA

B.1 CANADA

The most important deposits of manganese in Canada are of a primary sedimentary type that are found interbedded with sedimentary rocks of Cambrian age in Newfoundland and of Silurian age in New Brunswick.

The gently-dipping manganese-bearing beds that are in Middle Cambrian limestone, breccia, and shale are exposed at several localities along a strike length of about 6 km in the Avalon Peninsula and around Conception Bay, Newfoundland. Manganese carbonates and oxides occur as nodules, disseminated lenticles in the shale, and as massive, generally thin beds. The primary manganese carbonate is more or less surficially altered to pyrolusite and in some places secondary enrichment in manganese oxides has occurred. The manganiferous zone seldom exceeds 3.6 m in thickness of 12% manganese. At Manuels Brook, bulk samples representing a width of 3.05 m of nodular shale contained about 10% manganese and 5.5% iron. Samples across widths of 1.77, 2.38, 4.09, and 1.80 m contained 11.5, 10.73, 8.29, and 10.35% manganese respectively. At Brigus South Head on the west side of Conception Bay, a bulk sample from the central 46 cm of a manganiferous zone contained 33.35% Mn, 3.80% Fe, and 18.6% SiO_2.

In the Woodstock area of New Brunswick, manganese occurs in silicified slates and as manganiferous hematite iron formation. The manganiferous hematite is cut by quartz stringers, veinlets of rhodochrosite, and stringers of piedmontite. Minor axinite also occurs. The silicified slate contains rhodochrosite or manganiferous siderite, manganiferous chlorite, and hematite with subordinate amounts of axinite, piedmontite, and rhodonite.

The in-place resources in six deposits west of Woodstock are estimated at 193 million m.t. with an average grade of 13% iron and 9% manganese. These submarginal resources would be mined principally by underground methods, with an expected recovery of about 70%.

REFERENCES

Johnston, A.G. and McCartney, W.D., Manganese Occurrences in Canada, Geological Survey of Canada, Paper 64-37, 1965.

Economic Geology Report No. 1, Geology and Economic Minerals of Canada, Ed. R.J.W. Douglas, Geological Survey of Canada, pp. 333-334, 1969.

B.2 CUBA

The principal manganese occurrences are in south-central Oriente Province within a radius of 50 km of the port of Santiago. The manganese occurs both as bedded and irregular, nonbedded deposits associated with the volcanics and limestones of the Cobre formation of Paleocene-Eocene age. The bedded deposits contain the largest reserves and are generally found within the upper part of the Cobre formation. The bedded deposits are syngenetic, whereas the nonbedded deposits are associated with later faulting. The strike length of the largest bedded deposits was 1000 to 5000 m. Surficial deposits of manganese are scattered throughout the area. Ore grades on some of the larger bedded deposits were less than 20% manganese and in the nonbedded and surficial deposits they range up to 40 to 50% manganese. A reported 90% of the mine production has come from the bedded deposits and 4% from the surficial deposits. The manganese minerals included the primary oxides of the psilomelane group and the secondary oxides as manganite and pyrolusite. Silicates were reported in some deposits, but not carbonates.

During the early 1950's, the annual production was about 200,000 m.t. The last reported exports of manganese ore were 15,456 m.t. in 1969 (BOM, 1969). In 1972 it was estimated that 2.8 million m.t. of Mn units* occur in the Province of Oriente (W. A. Preston, British Steel Corporation, presentation to the panel, August 1979). The potential manganese areas have been extensively prospected and the chances are marginal for the discovery of any new large deposits. Cuba is not listed in the Resource Tables 3-7 or 3-8.

REFERENCES

Lewis, G.E. and Straczek, J.A., Geology of South-Central Oriente, Cuba, U.S. Geological Survey Bulletin 973-D, 1955.

U.S. Bureau of Mines, Minerals Yearbook, International, U. S. Government Printing Office, Washington, D.C., 1969.

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*"Manganese units," a commonly used mining and mineral purchasing term, is one percent of the manganese metal contained in an ore. A metric ton of ore containing 48 percent manganese would have 48 units of manganese of 22.05 pounds each.

B.3 UNITED STATES

The United States was a continuous producer of manganese ore until 1973, the last year of reported production. The production figures indicate a continual decline from 1957, when 332,426 m.t. were produced at a grade of 35+% manganese to 1973 with 31,000 m.t. The major manganese resources are found in six regions (locations #2 through 6 in Figure B-1) of the country and the tonnage and grade of these deposits are summarized in Table B-1.

TABLE B-1. MAJOR POTENTIAL MANGANESE RESOURCES WITHIN THE UNITED STATES

		Manganese content		
Resource	Amount of Ore(Million m.t.)	Contained Manganese (Percent)	Amount (Million m.t.)	Iron Content (Percent)
Aroostook County, Maine				
Maple Mt.-Hovey Mt.	260	8.9	23.2	20.7
North and South Districts	81	6.0 to 12.0	7.1	17.0
TOTAL	341	Avg 9	30	20.0
Artillery Peak, Arizona	159	3.9	6.2	3.0
Batesville, Arkansas	178	4.0	7.1	1.0 to 3.0
Chamberlain, South Dakota	>2,000	~0.6	>12.0	~1
Cuyuna Range, Minnesota	247	8.0	19.7	32.0
San Juan Mountains, Colorado	44	8.0	3.5	low

NOTE: Data from National Materials Advisory Board, 1976.

B.3.1 Cuyuna Range, Minnesota

The manganese deposits of the Cuyuna Range, Minnesota represent the most promising resource. The manganese occurs predominantly as carbonate and oxide minerals that are amenable to processing by hydrometallurgical methods, but are not amenable to physical beneficiation methods. The deposits are steeply-dipping, complexly folded, and erratically oxidized in varying degrees to depths of as much as 150 m or more below the surface. The potential manganese resources are predominantly of three types: 1) unoxidized, thin bedded iron formation (or "carbonate slate") with manganocalcite; 2) oxidized derivatives of "1" with manganiferous limonite, manganite, and psilomelane; and 3) oxidized, thick-bedded iron formation composed largely of thick-bedded cherts with manganese oxides.

Because the manganese minerals are interlocked intimately with the gangue minerals, attempts to beneficiate the manganese ore were not encouraging. Laboratory tests indicate that a high-grade concentrate can be obtained, but with very poor recovery. The deposits are conservatively estimated at 247 million m.t. averaging 8% manganese and 32% iron, using a cut-off of 2% manganese. Of the 247 million tons, 142 million m.t. are contained in 9 individual bodies ranging from 3 to 47 million m.t. with average grades ranging from 6 to 10% manganese.

B.3.2 Aroostook County, Maine

The significant manganese deposit in Aroostook County, Maine is located at Maple Mountain-Hovey Mountain. The deposit occurs as a manganiferous (silicate) sedimentary series of hematitic slates enclosing a banded hematite horizon. The rocks are complexly folded with some faulting. Particle size is extremely fine, with intimate admixture of the minerals so that physical beneficiation methods cannot be applied successfully. Braunite with hematite apparently is the principal manganese mineral. Rhodochrosite occurs with these two minerals as well as in laminae free of them. The central banded hematite contains 123 million m.t. of material, has an average thickness of 17.3 m, and averages 11.2% Mn, 23.9% Fe, 0.9% P, 25.4% SiO_2, and 7.61% Al_2O_3. The manganiferous hematite slates on either side of the banded hematite are estimated to contain 137 million m.t. and to have an average grade of 6.8% Mn, 17.9% Fe, 0.7% P, 36.0% SiO_2, and 11.43% Al_2O_3. Cryptocrystalline apatite is a constituent of the manganese-bearing formations.

The Strategic-Udy smelting process is described (Norman and Kirby, 1962) as being generally applicable to ferruginous manganese ores and low-grade ore concentrates assaying from 10 to 15% manganese. In the process, the phosphorus leaves the manganese and alloys with the iron, which is oxidized in a succeeding smelting operation to produce a low-phosphorus ingot iron and a high-phosphorus slag.

Deposits in the northern and southern districts of the county that could be mined by open-pit consist of manganiferous chlorite-carbonate rock or slate almost free of hematite. The manganese occurs as manganiferous ferruginous carbonates with possibly some bementite. Ore deposit is a very fine-grained manganiferous hematitic shale, with manganese occurring as braunite in dense aggregates with iron oxide and calcitic carbonate.

B.3.3 Batesville, Arkansas

The residual clay deposits of Batesville, Arkansas have produced 298,000 m.t. of manganese ore and 232,000 m.t. of ferruginous manganese ore. Production ceased in 1959. The remaining clays do not warrant further consideration. The protore is a gently dipping limestone with a manganiferous zone that ranges in thickness from about 3 to 15 m. Hausmannite and braunite are disseminated in a calcite gangue and also occur as replacement pods or lenses up to several centimeters thick. Small amounts of rhodochrosite are also present.

B.3.4 Artillery Peak, Arizona

The Artillery Peak, Arizona deposit, which is considered not to be a promising resource, consists of manganese oxides as part of the cementing material of sandstone and in intercalated clay beds. The manganese occurs in two stratigraphic zones separated by 228 to 305 m of essentially barren material. Only the upper zone was considered in the tonnage estimate. About 250,000 m.t. was mined prior to 1960, when production ceased.

B.3.5 San Juan Mountains, Colorado

The San Juan Mountains, Colorado deposits that are made up of rhodonite with minor rhodochrosite and are closely associated with gold-silver and lead-zinc-copper sulfide mineralization in numerous large, steeply-dipping veins have a very small potential and are not listed in Resource Table 3-8.

B.3.6 Chamberlain, South Dakota

The Chamberlain deposits in South Dakota are very low grade, averaging about 0.6% manganese. The manganese occurs mainly in the form of manganese-iron-magnesium carbonate concretions, averaging about 15.5% manganese in the bentonitic Pierre shale. The most promising manganiferous stratum varies in thickness from 3.6 to 26.2 m and has been traced for an outcrop distance of 844 km along the banks of the Missouri River and its tributaries. No satisfactory method has been devised to separate the concretions from the matrix. Furthermore, the grade is so low that it is not considered a resource from which manganese recovery is possible. The Chamberlain area is not listed in Resource Table 3-8.

A National Materials Advisory Board Panel in 1976 concluded that:

> "The United States has no domestic resource from which the manganese products suitable for steelmaking can be recovered economically and no facilities exist, or are planned, for recovering manganese from the low-grade manganese deposits that do exist.. The U.S. land-based manganese resources of significant size are very low in grade and should not be developed except in dire emergency, i.e., as a strategic resource."

REFERENCES

National Materials Advisory Board, Manganese Recovery Technology, NMAB-323, National Academy of Sciences, Washington, D. C., 1976.

Norman, L.D. and Kirby, R.C., Review of Major Proposed Processes for Manganese for United States Resources; Part I -- Pyrometallurgical Processes, I.C. 8138, U.S. Bureau of Mines., U.S. Government Printing Office, Washington, D. C., pp. 13-15, 1962.

BIBLIOGRAPHY

Dorr, J.V.N., Crittendon, M.D., Jr., and Worl, R.G., Manganese, United States Mineral Resources, USGS Professional Paper 820, U. S. Geological Survey, Washington, D. C., pp. 385-399, 1973.

Dupuy, L.W., Calhoun, W.A., and Rasmussen, R.T.C., Mining and Concentration of Missouri Valley Manganese at Chamberlain, South Dakota, R.I. 3839, U. S. Bureau of Mines, Washington, D. C., 1946.

Earl, K.M., and Eilertsen, N.A., Investigation of Manganese Deposits, Hodgdon and Linneus Townships, Southern District, Aroostook County, Maine, R.I. 6119, U. S. Bureau of Mines, Washington, D. C., 1962.

Eilertsen, N.A., Maple Mountain-Hovey Mountain Manganese Project, Central district, Aroostook County, Maine, R.I. 4921, U. S. Bureau of Mines, Washington, D. C., 1952.

Eilertsen, N. A., Investigation of the Littleton Ridge Manganese Deposit and Vicinity, Southern District, Aroostook County, Maine, R.I. 5104, U. S. Bureau of Mines, Washington, D. C., 1955.

Eilertsen, N. A., Investigation of Manganese Areas, Hammong Plantation and Hodgdon Townships, Southern District, Aroostook County, Maine, R.I. 5392, U. S. Bureau of Mines, Washington, D. C., 1958.

Eilertsen, N.A. and Earl, K.M., Bulk Sampling by Diamond Drilling, Dudley Manganese Deposit, Northern District, Aroostook County, Maine, R.I. 5303, U. S. Bureau of Mines, Washington, D. C., 1957.

Grout, F.F. and Wolff, J.F., Sr., Geology of the Cuyuna Range, Minnesota, Minnesota Geological Survey Bulletin 36, Minnesota Geological Survey, Minneapolis, 1955.

Lasky, S.G. and Webber, B.N., Manganese Resources of the Artillery Mountains Region, Mohave County, Arizona, USGS Bulletin 961, U. S. Geological Survey, Washington, D. C., 1949.

Lewis, W.E., Heising, L.F., Pennington, J.W., and Prasky, C., Investigation of Cuyuna Iron-Range Manganese Deposits, Crow Wing County, Minnesota, R.I. 5400, Progress Report 1, U. S. Bureau of Mines, Washington, D. C., 1958.

Marsden, R.W., Cuyuna District, Geology of Minnesota, Sims and Morey, Minnesota Geological Survey, Minneapolis, 1972.

Miller, R.L., Manganese Deposits of Aroostook County, Maine, Maine Geological Survey Bulletin No. 4, Maine Geological Survey, Augusta, 1947.

Pavlides, L., Geology and Manganese Deposits of the Maple and Hovey Mountain Area, Aroostook County, Maine, USGS Professional Paper 362, U. S. Geological Survey, Washington, D. C., 1962.

Pesonen, P.E., Tullis, E.L., and Zinner, P., General Investigations, Strategic Studies, and Tonnage and Grade Estimates, Missouri Valley Manganese Deposits, South Dakota, Part 1, R.I. 4375, U. S. Bureau of Mines, Washington, D. C., 1949.

Rothrock, E.P., Missouri Valley Manganese Deposits Between Lower Brule and De Grey, South Dakota Geological Survey R.I. 46, South Dakota Geological Survey, Vermillion, 1943.

Schmidt, R.G., Geology and Ore Deposits of the Cuyuna North Range, Minnesota, USGS Professional Paper 407, U. S. Geological Survey, Washington, D. C., 1963.

Stroud, R.B., Field Investigations, July 1956 to June 1961, Manganese Resources of the Batesville District, Arkansas, Part 3, R.I. 6478, U. S. Bureau of Mines, Washington, D. C., 1964.

White, W.S., Occurrence of Manganese in Eastern Aroostook County, Maine, USGS Bulletin 940-E, U. S. Geological Survey, Washington, D. C., 1943.

Young, W.E., Manganese Occurrences in the Eureka-Animas Forks Area of the San Juan Mountains, San Juan County, Colorado, USBM I.C. 8303, U. S. Bureau of Mines, Washington, D. C., 1966.

Zinner, P. and Grosh, W.A., Mining and Beneficiation Studies, Missouri Valley Manganese Deposits, South Dakota, Part 3, R.I. 4429, U. S. Bureau of Mines, Washington, D. C., 1949.

SOUTH AMERICA

B.4 ARGENTINA

Manganese deposits are known at a number of localities in Argentina, particularly in the northwest and western portions of the country. Most of the domestic manganese production has come from small mines in the Provinces of Santiago del Estero, Cordoba, and Mendoza. Lesser production has been reported from the Provinces of Salta, Jujuy, and Chubut. Production during 1974 to 1975 was reported to be 26,062 and 31,375 m.t. respectively, with grades ranging from 25 to 40% manganese. Imports in 1974 were 98,673 tons of plus 35% manganese, consumed largely in the production of ferro-alloys (BOM, 1974). With the startup of the underground manganese mine at Farellon Negro (Provincia Catamarca) in the early 1980's, with a projected production capacity of 25,000 tpy, it is anticipated that only 75% of the higher grades of manganese ore will have to be imported.

The manganese occurs variously as bedded deposits and lenses conformable with the bedding in aranaceous and volcanic sediments, as fracture fillings and vein deposits in sedimentary and volcanic rocks, and as residual surface deposits. The most important known manganese occurrence is located at Farellon Negro, where the manganese occurs as fracture fillings in a steeply dipping vein-like deposit that has a known vertical depth of 200 m and a length of 1 km. The vein thickness is variable, but ranges up to 12 m in complexly fractured zones. The internal structure of the vein is complex, with interfingered bands of carbonates and quartz with bands of oxides and limonite-hematite. The minerals include manganocalcite, rhodochrosite, ankerite, pyrolusite, and psilomelane. Silver and native gold are associated with an early phase of mineralization. Reserves for Argentina are listed as 2.1 million m.t. of manganese ore ranging from about 19 to 35% manganese. Of those reserves, about 765,000 tons of 29 to 35% manganese are reported in Farellon Negro (Cortelezzi, 1975).

REFERENCES

Cortelezzi, C.R., Los Yacimientos de Manganeso de la Republica Argentina, II Congreso Ibero-Americano de Geologia Economica, Vol. V., Department of Agriculture Scientific Publication. Buenos Aires, pp. 215-235, 1975.

Danieli, C. and Porto, J.C., Reseno Sobre Algunos Depositos de Manganeso en los Complejos Sedimentarios des Cretacio y Tèrciaro Superior en el Sector del NW Argentino, II Congreso Ibero-Americano de Geologia Economica, Vol. V, Department of Agriculture Scientific Publication, Buenos Aires, pp. 237-243, 1975.

Mining Magazine--Annuals, 1976-1979.

Tezon, V. and de la Inglesia, R.H., Deposito de Manganeso, Oro y Plata 'Farellon Negro,' Provincia, Catamarca, Argentina, Symposium on Manganese, Vol. III. 20th International Geological Congress, Mexico, pp. 417-434, 1956.

U.S. Bureau of Mines, Mineral Yearbooks, U. S. Government Printing Office, Washington, D. C., 1970-1975.

B.5 CHILE

Chile has been a consistent producer of manganese since the early 1920's. Annual production has ranged from only a few hundred tons during the mid-1930's to a maximum of 114,000 tons in 1943. The average yearly production from 1968 to 1975 was 23,000 tons, largely from the Province of Coquimbo, with lesser production from Antafagasto. Practically all of the manganese is consumed domestically.

There are four types of occurrences in Chile: 1) bedded deposits associated with continental sediments of largely tuffaceous sandstones, within a thick sequence of volcanics of L. Cretaceous age in Coquimbo Province; 2) lenticular masses and rocks in quartzites and Precambrian schists in Valdivia Province; 3) lacustrine deposits at high elevations near the border with Peru; and 4) vein types of occurrences at a number of the above localities and in northern Chile. Principal manganese minerals are pyrolusite, braunite, and psilomelane. In the Coquimbo deposits the individual manganese beds range in thickness from a few centimeters to several meters with an average from one-half to one meter. Several beds may be intercalated with other sediments to make layers with overall thickness of up to 20 m. Reserves have been inferred to be 1.0 million m.t. of 42% manganese and 1.5 million tons of 23% manganese (Weiss, 1977).

The long period of manganese production from diverse localities in Chile would tend to minimize the possibility of any new, large-scale discoveries.

REFERENCES

Ruiz, C.F., Geologia y Yacimientos Metaliferos de Chile, Instituto de Investigaciones Geologicas, Chile, 1965.

Ruiz, C.F. and Ericksen, G., Metallogenetic Provinces of Chile S.A., Economic Geology 57, 91-106, 1962.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books Ltd, Garden City Press, Ltd., Hertfordshire, U. K., 1977.

B.6 COLOMBIA

Manganese has been reported from a number of localities throughout the country in the Departments of Narino, Caldas, and Antioquia in southwest and west-central Colombia. The occurrences have been described as lenses and stringers in siliceous, fine-grained chloritic schists; intercalations in siliceous and clayey shales; and intimately interbedded lenses in marine cherts. Reserves are generally not reported, but at Ciudad Pasto, Departmento de Narino, they were estimated to be able to support an annual production of 20,000 m.t. for 10 years (ILAFA, 1971). In Caldas, chip samples from stockpiled, hand-sorted ore assayed 36.4% Mn, 4.6% Fe, and 25.8% SiO_2. Ore minerals were psilomelane and pyrolusite (Singewald, 1950). Reported manganese production ranged from 6,000 to 14,000 m.t. annually during 1973 to 1976 (BOM, 1973-1976) with all of the production for domestic consumption. The prospects of developing large reserve tonnages appear to be minimal. Colombia is not listed in Resource Tables 3-7 or 3-8.

REFERENCES

Mercado y Estructura de la Industria Siderurgica en Columbia, Instituto Latinoamericano del Hierro y el Acero (ILAFA), Santiago de Chile, 1971.

Resumen Anticipado de los Recursos Minerales en las Zonas Del Programa de Investigaciones Geologico Mineras 1964-1968, Republic de Columbia Ministerio de Minas y Petroleos, Inventario Minero Nacional, en colaboracion con la Agency for International Development y el U.S. Geological Survey, October 1968.

Singewald, Q.D., Mineral Resources of Colombia, U.S. Geological Survey Bulletin 964-B, U.S. Geological Survey, Washington, D. C., 1950.

Tschanz, C.M., Andres, J.V., and Jaime, C.B., The Mineral Resources of the Sierra Nevada de Santa Marta, Colombia (Zone I), U.S. Geological Survey Project Report, Colombian Investigations IR CO-11, U. S. Geological Survey, Washington, D. C., 1970.

U.S. Bureau of Mines. Minerals Yearbooks, Washington, D.C., U.S. Government Printing Office, 1973-1976.

Wokittel, R. Recursos Minerales de Colombia, Ministerio de Minas y Petroleos, Republica de Colombia, 1970.

B.7 GUYANA

There has been no recorded production of manganese in Guyana since 1968 when the mine at Matthews Ridge closed. This mine, which was located in northwestern Guyana between the Barama and Barima rivers, about 6 km south of the settlement of Arakaka, operated from 1960 to 1968 and was closed because of its unprofitability. During that period, it produced 1,506,800 m.t. of concentrates at a grade of 40 to 42% Mn and 17 to 25% SiO_2. The initial reserves were estimated at about 13 million m.t.

At Matthews Ridge, pyrolusite-polianite, cryptomelane, and manganite with lithiophorite occur as superficial, enriched, residual cappings on gondite plus braunite protore. The primary manganiferous zone is about 150 to 175 m thick at Matthews Ridge and is approximately 30 km long in a general NE-SW direction. The dip of the beds is 50 to 80° north. In the Matthews Ridge area, the rhodonite-bearing gondite beds, 1 to 10 cm thick, are intercalated with quartzite and quartz-sericite schists, with carbonaceous horizons in the Barama Series. Beds of braunite up to 1.5 m thick are intercalated with metamorphosed chert.

Depending on the crude to product weight recovery, a resource of about 10 million tons may remain to give approximately 6 million tons of product at the above grade. A submarginal resource of low-grade protore exists, but quantities and grades are not known. However, it consists in larger part of the refractory minerals, rhodonite and spessartite, that are not usable. Therefore, it may be presumed that Matthews Ridge with its poor location and lack of adequate transportation, is an unlikely source of manganese. Other deposits occur in Guyana, but they are all small or low-grade.

REFERENCES

Chaubert, B., Occurrences of Manganese in the Guianas (South America) and Their Relation with Fundamental Structures, Genesis of Precambrian Iron and Manganese Deposits, Earth Sciences, 9, UNESCO, Paris, pp. 143-152, 1973.

Holtrop, J.F., The Manganese Deposits of the Guiana Shield, Economic Geology 60, pp. 1185-1212, 1965.

Roy, S., Ancient Manganese Deposits, Handbook of Strata-Bound and Stratiform Ore Deposits, Vol. 7, Ed. K.A. Wolf, Elsevier Scientific Publishing Company, Amsterdam, pp. 416-417, 1976.

U.S. Bureau of Mines, Minerals Yearbooks, U.S.Government Printing Office, Washington, D. C., 1960-1968.

B.8 PERU

The principal manganese producer has been the Mina Gran Bretana, located near Negro Bueno in the Department of Junin in Central Peru at a map distance of 170 km east northeast of Callao. The mine site is at an elevation of about 4,100 m. Annual production from 1960 to 1977 averaged 3,900 m.t. with annual fluctuations ranging from 400 to 11,000 m.t. Average annual grades ranged from 36.2 to 27.8% manganese. Production from Gran Bretana, as Peru's sole producer, terminated in 1977, apparently with the exhaustion of reserves. The deposits are believed to be associated with vein-type occurrences in fractured rocks near granitic intrusives.

Manganese has also been reported as scattered residual accumulations and boulders near La Merced, Department of Junin, on the lower eastern slopes of the Andes Mountains, at a map distance of 250 km east of Callao. The mineralogy of the boulders includes pyrolusite, psilomelane, and braunite. Selected samples contained 55% manganese. Tonnage potential was inferred to be 60,000 m.t. (de Graff, 1955).

At the Mina Berenguela, situated at an elevation of 4,200 m near Sta. Lucia in the Department of Puno near Lake Titicaca, manganese occurs as a gangue mineral associated with deposits of copper and silver. During 1940 to 1950 attempts to recover the manganese as a byproduct were unsuccessful and the effort was terminated. Peru is not listed in Resource Tables 3-7 or 3-8.

REFERENCES

de Graff, E., Discovery of Extensive Manganese Deposits in the Perene Region of East Central Peru, Peruvian Times XVIII/#939, Lima, Peru, December 12, 1958.

Plan Regional Para el Desarollo del Sur del Peru, Vol. II Los Recursos Minerals, Ministerio de Hacienda y Comercio, Lima, Peru, pp. 103-107, 1959.

U.S. Bureau of Mines, Minerals Yearbooks, U. S. Government Printing Office, Washington, D. C., 1955-1977.

B.9 VENEZUELA

The manganese occurrences are located in Estado Bolivar in southeastern Venezuela. They are found in a belt lying about 40 km south of and parallel to the Rio Orinoco. They extend from the Rio Caura on the west to the eastern end of the Serrania de Imataca, an overall length of about 320 km. The principal manganese prospects are found along this belt between the towns of Upata and El Palmar. Manganese occurrences have also been reported in the San Cristobal area of the upper Rio Botonamo, in the eastern portion of Estado Bolivar near the frontier with Guyana (Aguilar, 1972).

A mine production of 47,000 m.t. was reported from the Upata district for the period 1956 to 1958. Twenty-two thousand tons were exported through the port of Aramaya, located on the Rio Orinoco, 10 km east of San Felix, at a truck haul distance of 80 km from the mine site.

In the Serrania de Imataca the manganese oxides occur as discontinuous surficial residual accumulations on the manganiferous members of the Precambrian Imataca group of metasediments consisting of iron formations, amphibolites, and schists. In the San Cristobal area the manganese concentrations are associated with the ferruginous quartzites, dark phyllites, chloritic schists, and siltstones of the Precambrian Pastora group.

The manganese occurrences were reported in 1949 and have been the subject of intermittent investigations throughout the Serrania de Imataca since that time. Probable reserves totalling 350,000 tons of 28 to 55% manganese have been credited to the Upata district (Steel, 1955; Skillings, 1959).

REFERENCES

Aguilar, R. A., Estudio Preliminar de los Yacimientos Manganesiferos del Cerro San Cristobal, Region Cuenca Norte del Rio Botanamo IV Congreso Geologico Venezuela Tomo IV, Caracas, 1972.

Balestrini, C. C., Economia Minera y Petrolera, Universidad Central de Venezuela, Caracas, 1959.

Holtrop, J.F., The Manganese Deposits of the Guiana Shield Econ. Geol. 60, pp. 1185-1212, 1965.

Levi, M., Venezuela y Sus Recursos, Ediciones Cultural Venezulana, Caracas, 1964.

Menendez, A., Geologia de La Region de Guasipati, Guayana, Venezuela, Memoria, Cuarto Congreso Geologica Venezolano, Vol. IV, Caracas, pp. 2001-2046, 1972.

Steel, Manganese in Venezuela Steel (now known as Industry Week, Cleveland), Aug. 1, 1955.

Skillings, Manganese Ore in Venezuela Skillings Vol. 48, Duluth, Minn., Nov. 14, 1959.

EUROPE

B.10 BELGIUM

The only significant manganese resource occurs in the Lienne Valley, in the area between Bienleux and Meuville, near the Luxembourg border. Two irregular bands of manganese carbonates and silicates, ranging from 0.7 to 1.10 m thick and 30 to 45 m apart in quartzite, are associated with some hematite. The upper bed is intermittent. Series dips south at 40°. The resource contains 7 to 16% manganese, uniformly high (0.25%) P, 18 to 25% Fe, and 25 to 45% SiO_2. This material was mined for the local steel industry as early as 1886 and maximum production occurred in 1896 (28,272 m.t.). Marginal in times of scarcity or high price (i.e., World War I), production ceased in 1934 after a total of 144,431 m.t.

Potential resources of the above grade appear to be ferruginous ore and are estimated at 1 million m.t. in place to a depth of 200 m. This might yield 500,000 m.t. of recoverable material containing 50,000 m.t. of manganese.

REFERENCES

Ancion, C., Calembert, L., and Macar, P., Les Ressources en minera de manganese du sous-sol de la Belgique, Symposium on Manganese, Vol. V., XXth International Geological Congress, Mexico, pp. 9-15, 1956.

B.11 CZECHOSLOVAKIA

The minor national production has come from the Kisovce and Svabovce areas, between the Low and High Tatras in northeastern Slovakia. A thin layer of rhodochrosite, pyrolusite, and manganocalcite occurs in Oligocene limestone, sandstone, and shale. Manganese ranges from 15 to 25%; iron 1 to 2%. Output was 252,000 m.t. in 1954, 165,000 m.t. in 1960, and is now almost nil. Supplies now come from Brazil, Gabon, and India. It is presumed that economic reserves are insignificant. A submarginal manganese resource of minor potential is the Chvaletice manganese-carbonate-pyrite deposit in eastern Bohemia. Volcanosedimentary syngenetic manganese in veins has been metamorphosed to hornfels with manganese silicates. Some carbonate remains. Deposit is up to 30 m thick and assays 12 to 18% Mn, 20 to 30% Fe, 15% SiO_2, 8 to 12% S, and 1.6% P. Trace amounts of base metals, the high P and S, and the mixture of silicate and carbonate make the economic potential paramarginal, although the host schists occur over more than 20 km^2. Czechoslovakia is not listed in the Resource Tables 3-7 or 3-8.

REFERENCES

Mining Journal, The Location of Czech Mineral Centres, 254, 536, 1960.

Pouba, Z., Manganese Ores in Czechoslovakia, Symposium on Manganese Deposits, XXth International Geological Congress, Mexico, pp. 19-23, 1956.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books Ltd., Garden City Press Ltd., Hertfordshire, U. K., 1977.

Zak, L., Report on Recent Work in Manganese Ore Researches in Czechoslovakia (1966-1970), Acta Mineralogica-Petrographica, Szeged XX/1, 181, 1971.

B.12 GREECE

Manganese has been produced in Greece for about 100 years; however, the production has never been large. The ores are not mined for metallurgical use but for battery-grade material. The 27-year production from 1950 to 1976 has been as shown in Table B-2.

TABLE B-2. PRODUCTION OF MANGANESE ORES IN GREECE FROM 1950 TO 1976 (metric tons)

Year	Ore Production	Production in Concentrates	Concentration Ratio
1950-1959	437,353	78,803	5.5
1960-1969	619,671	163,678	3.8
1970	31,865	6,590	4.8
1971	35,463	6,127	5.8
1972	24,353	5,305	4.6
1973	42,433	6,222	6.8
1974	52,091	7,950	6.5
1975	45,248	11,318	4.0
1976	58,248	10,924	5.3

SOURCE: Weiss, 1977.

The largest manganese mines in Greece are located in the Drama area in eastern Macedonia, where production of battery-grade material began in 1950 at the Granitis and Paramesti mines. The ore occurs as pyrolusite at the contact between limestone and micaceous schists and as pods localized near faults where the ore thickens. The deposits are erratic in shape and distribution so that it is difficult to prospect and develop reserves ahead of mining. The run-of-mine ore with a grade of about 19 to 28% manganese is beneficiated at Nevrokopi to 67% MnO_2 and 74 to 75% MnO_2. A typical analysis of the concentrate is as follows: 47% Mn, 71% MnO_2, 0.8% Fe, 7.5% SiO_2, 5% CaO, and 0.5% Cu+Pb+Zn. The final product, ground at Drama, is shipped from the Port of Kavala (Weiss, 1977).

The total Greek reserves of manganese (Sibley, 1973), including metallurgical grade ore (which is not mined), is estimated at 2.25 million m.t. proven and 9 million m.t. probable. The grade is not specified. A plant, installed about 1975 with a 12,000 tpy capacity, is to produce electrolytic manganese dioxide for use in dry cell batteries and initially will obtain its concentrates from the Chalkidiki Peninsula in northern Greece. Greece is not listed in the Resources Tables 3-7 or 3-8 because grades were not given.

REFERENCES

E.J. Lavino and Company, Manganese, Nature, Sources, Markets, E.J. Lavino and Company, Philadelphia, Pa., undated.

Sibley, S.F., The Mineral Industry of Greece, Minerals Yearbook, Vol. III: Area Reports, International, U. S. Government Printing Office, Washington, D. C., pp. 369-380, 1973.

Sondermayer, R.V., The Mineral Industry of Greece, Minerals Yearbook, Preprint, U. S. Government Printing Office, Washington, D.C., 1976.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books Ltd., Garden City Press Ltd., Hertfordshire, U. K., 1977.

B.13 ITALY

Manganese occurrences have been recorded throughout Italy and Sardinia; however, the principal source in recent years has been near La Espejas in the Province of Ligurica in northwestern Italy. Most of the manganese occurrences are associated with sedimentary rocks including shales, bedded cherts, and limestones. At Gambetsas the ores consisted of enriched caps of pyrolusite on lens-like beds of braunite and quartz, intercalated in shaly-cherty, calcareous sediments. The protore lenses were up to 500 m in length and 10 m in thickness. The host sediments have been moderately folded by Alpine-related tectonics.

The Gambetsas Mine had an annual production range of 10,000 to 30,000 m.t. from the mid-1930's until the cessation of mining in 1975. Mining ceased at Gambetsas due to the depletion of reserves. It was the last operating manganese mine in Italy. The estimated ore grades for the last years of production were about 27% manganese. Manganese in ferruginous manganese ore was also produced from Monte Argentario in the Province of Grosseto, where it occurred in surficial ores developed on primary deposits of mainly sulfides of hydrothermal origin. The geologic literature indicates that there were many small-scale manganese mining operations during the last 100 years in Italy, from which it can be inferred that the country has been prospected and that the changes for new discoveries are minimal.

Italy is not listed in the Resource Tables 3-7 or 3-8.

REFERENCES

Burkhardt, C.E. and Filippo, F., Memoria Sui Giacimenti Italiani Di Manganese, (Memoir of the Manganese Deposits of Italy), Symposium on Manganese Deposits, Vol. V, 20th International Geological Congress, Mexico, 1956.

U.S. Bureau of Mines, Minerals Yearbook. Vol. III, U. S. Government Printing Office, Washington, D. C., 1975.

Quattrociocchi, Dr. Ing. Tullio, Italy, Mining Annual Review, Mining Journal, London, p. 530, June 1976.

B.14 ROMANIA

Manganese ore mining has a long history in Rumania starting in 1780 in northeast Moldavia. Thirty scattered deposits were mined sporadically from manganese oxide outcrops, with an aggregate production up to 1955 of 2.5 million m.t., grading from 28 to 42% manganese. Under the Socialist regime, manganese exploration was intensified and new, small, steeply-dipping deposits were found in numerous localities in the Carpathians. Ore is now mainly manganese carbonate and silicates, mined at depths at 170 m or more from steeply-dipping lenticular faulted ore bodies. Since 1952 carbonate ore has been sintered, raising crude ore from 26% manganese and 11% iron to 34 to 38% manganese and 14% iron. Such production is quite siliceous, in the order of 25% SiO_2. Most domestic ores have the disadvantage of high phosphorus, from 0.25 to 0.9%.

All deposits are in the Alpine-folded area of the Carpathians, extending from Iacobeni area near the USSR border in northeast Moldavia to the southeastern Banat, near the Yugoslavian border.

B.14.1 Iacobeni Area

The Iacobeni area includes Dadu-Ciocanesti-Iacobeni-Cosna-Sarul, Dornei-Dealul, and Rusului-Borca. Ores are characterized as having moderate iron and Mn carbonate and silicate minerals. Deposits are lenticular, confined to black quartzite horizons of Proterozoic age in crystalling greenschists dipping 20° to 40° E. Lenses range from tens of meters to several hundred meters long and from one meter to several tens of meters thick. South-dipping E-W faults complicate underground mining development. Genesis is volcanosedimentary. Aggregate lens lengths are about 3,000 m. Potential in situ is evaluated in this review at 15 million m.t. of carbonate ore to a depth of 150 m vertical, with chemistry of 26% Mn, 11% Fe, 26% SiO_2, 0.27% P, and 0.26% S. Sinter has a similar chemistry. In view of the dip, thickness, discontinuities, grade, and impurities, the deposits must be marginally economic. It is noteworthy that Rumanian imports of good oxide ore from western countries have been increasing since 1970. Recoverable resource potential, considering the amount mined to date, may be about 1.26 million m.t. of sinter product.

B.14.2 Razoare Area

South of Baia Mare, in the Preluca Mountains, the lense-like deposits are encased in highly metamorphosed crystalline schists. Manganese oxides and hydroxides were mined from the late 1700's until 1918. Oxide production from 1905 to 1918 was about 18,300 m.t. Present ore is characterized as siliceous ferromanganiferous; mineralogy includes manganese carbonates, manganese silicates, and some manganese and iron oxides. Average analysis is 19% Mn, 20% Fe, 16.6% SiO_2, 0.88% P, and 1.29% S. Excessive phosphorus and sulphur would make this material a resource in modern usage. On the basis of geophysics, lenses 200 m long extending over 2.5 km are assumed to extend perhaps 750 m down at a southeast dip 20° to 70°. Thickness ranges from 1.5 to 27 m. Development has been by adit. The panel estimates underground potential at 5 million m.t., with about half recoverable.

B.14.3 Moneasa Area

Located southwest of Cluj, this residual resource consists of manganese oxides and limonite in clay in Triassic karst topography. Manganese is about 7%, iron about 21%, and potential is insignificant.

B.14.4 Banat Area

Found between Turnu Severin and Timisoara, these regionally metamorphosed volcanosedimentary deposits include Globu Rau and Delinesti. The latter has been mined for its oxide ore since the last century. To 1955, aggregate oxide production was 556,000 m.t. Globu Rau has been known since the beginning of the 1900's and prospecting was intensified in 1953.

Manganese mineralization outcrops intermittently in the Delinesti area over 5 km. Lenses range from ten to several hundred meters long, with perhaps the same extension down dip. Thickness ranges from 1 to 8 m. Ore is characterized as high silica type; primary carbonate occurs only locally and the material is high in manganese and iron silicates. Characteristic assay is 20% Mn, 10% Fe, 37% SiO_2, 0.10% S, and 0.22% P. From the map, in situ material might be calculated at 7.5 million m.t., of which 4.5 million m.t. may be recoverable. However, it is a low-grade or submarginal resource.

B.14.5 East of Arad

This area includes Soimus-Buceava and Pirnesti. There are alternating layers of manganese oxide and jasper, with radiolaria, somewhat similar to east Cuban marine volcanosedimentary deposits. Iron is quite low and manganese occurs as oxides, psilomelane, and pyrolusite reaching 27%. Silica is about 35%. Potential is believed small.

B.14.6 Sebes Mountains

Manganese deposits occur as 7-24 m. thick concordant lenses in mica schists which crop out over a distance of 4 km midway between Timisoara and Brasov (Ianovici, 1956, 1968). Manganese is present as silicate refractory minerals, viz: garnets, amphiboles, olivine and rhodonite. These are locally covered with a capping of a few centimeters thick of pyrolusite and wad which averages 22% Mn, 10% Fe, 38% SiO_2 and 0.3% P (Dimitrescu, 1971). The mineralized zone is cut by transverse faults. The possibility of beneficiation is minimal.

REFERENCES

Dimitrescu, R., Progress Report on Research in Manganese Ore Deposits of Romania, Acta Mineralogica-Petrographica XX/1, 179-180, 1971.

Ianovici, V., Information Generales sur les gisements de minerai de manganese de la Roumanie, Symposium on Manganese Deposits, Vol. V, XXth International Geological Congress, Mexico, pp. 349-373, 1956.

Ianovici, V., Constantinof, D., Draghici, C., Ionescu, C., and Dimitriu, A., Geology of Manganese Deposits in Rumania, XXIII International Geological Congress, Vol. 13, Czechslovakia, pp. 269-278, 1968.

B.15 SPAIN

Manganese ore has been mined in Spain since the mid-1800's. Although ore has been mined from many of the provinces throughout the country, the principal domestic source area has been the Province of Huelva in southwestern Spain. A peak annual production of 268,000 m.t. was reported in 1897, but it has decreased irregularly since that time. In 1973 the total domestic production was listed as 6,792 m.t. (BOM, 1960-1977) and by 1975 no domestic ore production was recorded.

The principal manganese occurrences in Huelva were described as pockets of manganese oxides with a general vein-like alignment along the contacts of jaspers and Silurian slates. Disseminated pockets of manganese were also reported within the jaspers and were known to depths of 140 m. Average analyses of these oxide ores was 40% Mn and 25% SiO_2 (Pastor et al., 1956). At some localities the manganese oxide ores give way at depth to carbonates that have an average analysis of 30% manganese. The deposits were considered to be of hydrothermal origin and were frequently associated with, and oriented parallel to, deposits of massive pyrite.

In the province of Ciudad Real, manganese occurred as blanket-like deposits of pyrolusite, with clays and micaceous sands at the water table in Miocene shales, sandstones, and calcareous rocks. The deposits were mined both by underground and open-pit methods. The beneficiated product varied from 30 to 52% Mn and averaged 15% SiO_2, 3% Fe, and 0.45% P. In the province of Gerona in northeastern Spain, small deposits of pyrolusite were reported from Silurian limestones.

Manganese has been known and prospected throughout Spain for many years. The cessation of significant production suggests that the reserves of oxides are depleted. The potential of carbonate ores is not known. Spain is not listed in the Resource Tables 3-7 or 3-8.

REFERENCES

de la Concha, S. and Feito, J.S., Guia del Mapa Minero de Espana, excluidos hierro y carbon, Escala 1:1,000,000, Notas y Comunicaciones del Instituto Geologico y Minero de Espana, No. 62, 1969.

Pastor, M., Doetsche, J., de Lizaur, J. and de la Concha, S., Criaderos de Manganeso de Espana, Symposium on Manganese Deposits, Vol. V. XXth International Geological Congress, Mexico, 1956.

U.S. Bureau of Mines, Minerals Yearbooks, U. S. Government Printing Office, Washington, D. C., 1960-1977.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books Ltd., Garden City Press Ltd., Hertfordshire, U. K., 1977.

B.16 SWEDEN

The last manganese ore mined in Sweden was in 1966 when 21,650 m.t. of manganese ore with 13% manganese was mined from the Nyberget deposit. No mining has taken place in recent years. Manganiferous iron ores, with a manganese content usually varying between 2 and 5%, are being obtained from central Sweden.

The Nyberget field, in the Filipstad district of southern Sweden, contains several small deposits of skarn-banded hematite ores with manganese silicates that grade 15 to 20% of both manganese and iron. Rhodonite and hematite are in thin alternating layers. Braunite, hematite, and jacobsite with a series of skarn minerals occur in a newly discovered continuation of the field to the south (Grip, 1979).

The Langban mines, also in the Filipstad district, produced 318,000 m.t. of manganese ore in the period 1925 to the late 1950's. In the last period worked, the ore graded 12 to 38% manganese. The Langban mines are famous for the abundance of mineral species, with at least 135 minerals being described. The deposits are replacement bodies of manganese and iron oxide that are side by side in a large dolomite mass. The iron ores seldom exceed 2% manganese and the manganese ores seldom exceed 2% iron. The manganese oxide ore consists of braunite, which occurs principally at the center of the orebodies, and of hausmannite, which is at the periphery.

It is presumed that the resource of manganese ore is small because of the restricted nature of the known deposits. Sweden is not listed in the Resource Tables 3-7 or 3-8.

REFERENCES

Grip, E., Sweden, Mineral Deposits in Europe, Vol. 1, Northwest Europe, Ed. S.U. Bowie, Institution of Mining and Metallurgy, London, pp. 103, 120, 122, 1979.

Vober, F.M., Introduction, In Mineral Deposits in Europe, Vol. 1, Northwest Europe, Ed. S.U. Bowie, Institution of Mining and Metallurgy, London, p. 19, 1979.

B.17 UNITED KINGDOM

There has been no manganese mined in the United Kingdom since 1945, with the last recorded production from Caernarvonshire, Wales. The few manganese occurrences in the United Kingdom are comparatively low-grade material with relatively modest tonnage. The resources of manganese may all be put into the "strategic" category and would not be drawn on unless in dire emergency (W.A. Preston, British Steel Corporation, presentation to the Committee, August 1979).

There are two occurrences in southwest England. In the Milton Abbot area (Dines, 1956), psilomelane and rhodonite with secondary pyrolusite and wad occur as pockets and stringers in irregular bodies. They are an alteration or impregnation of the more siliceous beds in the Lower Culm Measures near the junction of the Devonian and Carboniferous zones and are closely associated with intrusive greenstone. The area has produced 51,426 m.t. In the Exeter area (Dines, 1956), pyrolusite, with surface oxidation to psilomelane with wad, occurs in a fault fissure in Permian sandstone and breccia.

In Caernarvonshire, Wales, a manganese bed (Groves, 1952) in Ordovician mudstone has been broken, by intense intricate shearing, into numerous separate bodies contained in blocks from a few centimeters up to 10 meters or more thick. The bed has a thickness of 2.5 to 6 m and in places is thickened by repeated overthrusting. The mineralization consists of a complex mixture of manganese silicates with subsidiary manganese and iron oxides. The total resource estimate is given as 27,000 m.t. at a grade of about 32% manganese. Exploration has not revealed extensions to the known bodies. About 217,000 m.t. have been extracted from this area.

A thin bed (25-37 cm) of fine-grained chert, rhodochrosite and spessartite occur in the Lower Cambrian beds over an area of many square kilometers in the Ardudwy District of Merionethshire, Wales. The bed was worked until 1923 and total production amounted to about 40,000 m.t. at a grade of between 32 to 35% manganese (Woodlawn, 1956). Wad occurs in Derbyshire, Midlands in flats, pipes and pockets in Carboniferous limestone and was formerly worked on a very small scale.

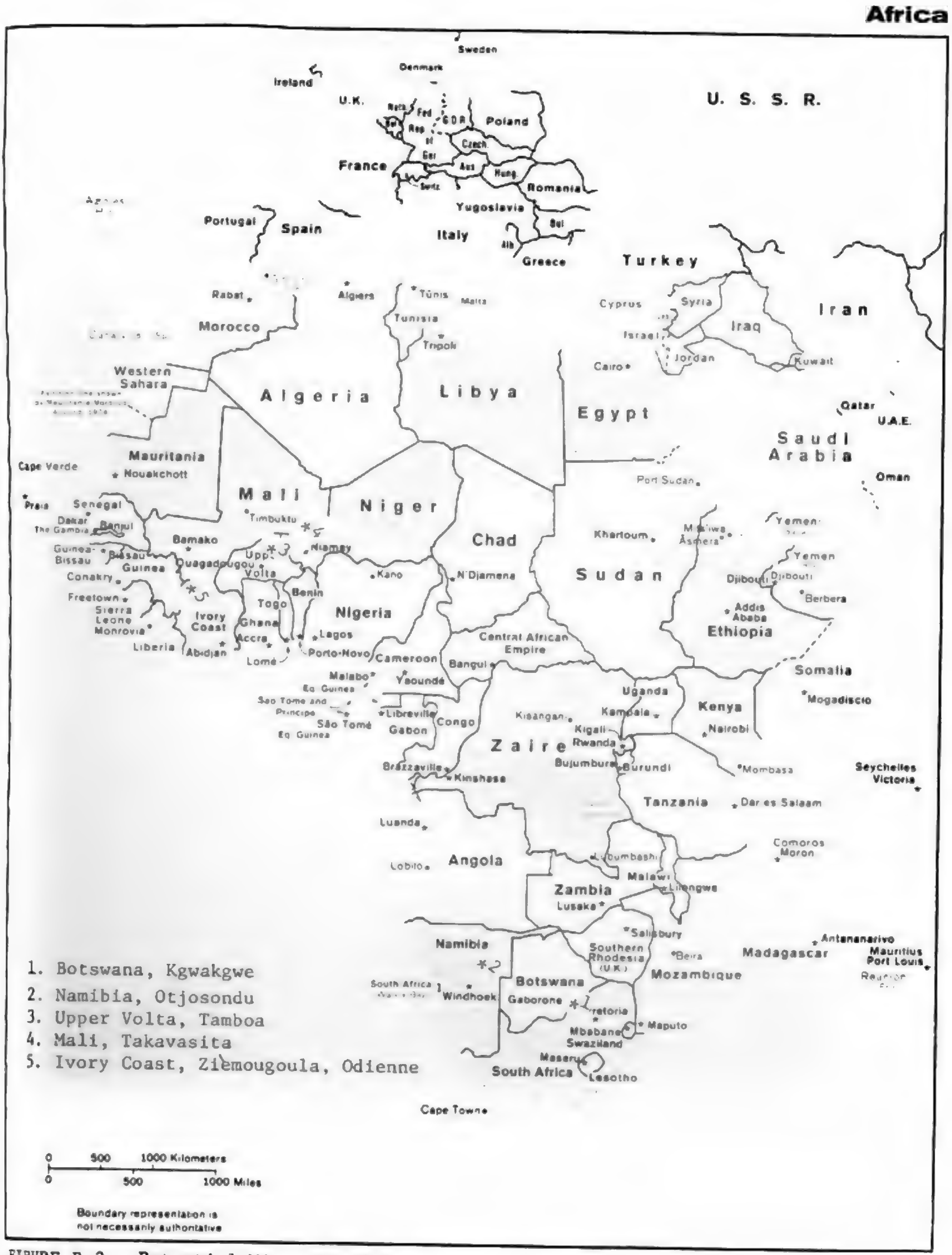
The United Kingdom is not included in the Resource Tables 3-7 or 3-8.

REFERENCES

Dines, H.G., The Metalliferous Mining Region of Southwest England, Memoir, Geological Survey, Vol. 11, London, 1956.

Groves, A.W., Wartime Investigations into the Haematite and Manganese Resources of Great Britain and Northern Ireland, Ministry of Supply, Permanent Records of Research and Development No. 20, 703, London, 1952.

Woodland, A.W., The Manganese Deposits of Great Britain, Symposium del Manganeso, XX Congresso Geologico Internacional, Tomo V, Europa, Mexico, pp. 197-218, 1956.



1. Botswana, Kgwakgwe
2. Namibia, Otjosondu
3. Upper Volta, Tamboa
4. Mali, Takavasita
5. Ivory Coast, Ziemougoula, Odienne

FIBURE B-2. Potential Mines in Africa

B.18 ANGOLA

The principal manganese areas are near Salazar and Malange, about 200–300 kilometers east of the port of Luanda to which they are connected by rail. The ores occur in discontinuous lenticular and vein-like deposits with some residual accumulations. The ores are high in silicates and sulphur with variable high concentrations of lead. The principal minerals are massive psilomelane with some admixed manganite. Reserve tonnage potential is small. Exports of 27%-52% manganese ore averaged 27,000 tons annually from 1968-1973, at which time all exports ceased due to civil unrest (BOM, 1976). Ore quality was controlled by hand sorting.

Angola is not included in Resource Tables 3-7 or 3-8.

REFERENCES

deKun, N. Mineral Resources of Africa, Elsevier Scientific Publishing Company, Amsterdam, 1965.

Pelletier, R.A., Mineral Resources of South-Central Africa, Oxford University Press, New York, 1964.

U.S. Bureau of Mines, Mineral Industries of Africa, U. S. Government Printing Office, Washington, D. C., 1976.

B.19 BOTSWANA

The principal manganese occurrences in Botswana are at Kgwakgwe near Kanye and Lobatse, about 70 kms SSW of Gaborone. Lobatse is connected by rail to South Africa through Mafeking. The manganese occurs in botroidal masses and as thin-bedded deposits and replacements in manganiferous shales of the Transvaal Series (Pelletier, 1964). The manganese beds range in thickness up to two meters and are discontinuous along strike. Operations were by quarrying and by underground with handsorting of ore boulders. Ore grades at Kgwakgwe, the principal mining area, ranged from 46.2-57.9% manganese. At Kgwakgwe, mining commenced in 1957 and was terminated in 1972 due to economic conditions. A total of 131,563 tons were produced and shipped. A reported reserve of 200,000 tons remains (Baldock, 1977).

In the vicinity of Palapye, 260 kms NNE of Gaborone, supergene manganese crusts with widths of up to 2.5 meters and thicknesses of less than 5 cm are scattered along the exposed and weathered surface of low-grade manganiferous beds with overall thicknesses of up to 20 meters. The strike length of the exposed beds is 40 and 55 kms respectively in the Tswapong and Tsweneng Hills east of Palapye. The mineralogy of the manganese crusts is psilomelane, hematite and quartz. Analyses of 390 channel samples collected along the strike length of the beds ranges from 1-30% manganese and 2-22% iron. In the underlying unweathered rock, the manganese occurs in millimeter-thin laminae interlayered in silts, mudstones and fine-grained quartzites. Both Samancor and the Geological Survey consider these occurrences to be of doubtful economic potential (Key, 1979). The Palapye occurrences are not listed in the Resource Tables 3-7 or 3-8.

REFERENCES

Baldock, J.W., Resources Inventory of Botswana: Metallic Minerals, Mineral Fuels and Diamonds, Geological Survey Department, Rep. of Botswana, 1977.

Key, R.M. B.Sc., Ph.D., M.I.M.M., Stratiform Manganese Mineralization in the Palapye Group, eastern Botswana, Transactions, Institution of Mining and Metallurgy, Vol. 88, Sec. B, London, 1979.

Pelletier, R.A., Mineral Resources of South-Central Africa, Oxford University Press, Amen House (Capetown), London, 1964.

B.20 EGYPT

The Um Bogma manganese deposits are located on the western side of the Sinai Peninsula, about 20 km inland, east of the Gulf of Suez port of Abou Zenima. The manganese deposits occur as lenses within the lower 6 m of a 20-m-thick bed of dolomite and marly dolomites. The manganese lenses vary in length from 1 to 200 m and in thickness from 0.2 to 6 m. According to Mart and Sass (1972) the large orebodies are differentiated into three zones. The inner zone, which grades greater than 45% manganese, is largely composed of psilomelane and pyrolusite, with rare manganite, hausmannite, polianite, and pyrochroite. Hematite does not usually exceed 10%. The intermediate zone, grading 20 to 45% Mn, consists mainly of psilomelane, pyrolusite, and hematite. The mineralization is massive and crossed by veins of pyrolusite-barite with or without quartz. This zone was the major source of the ore produced. The outer zone, less than 20% manganese, is composed mainly of hematite and goethite, with minor psilomelane.

The occurrences are of a volcanogenetic type and of small potential. The average grade of the ore lenses, when mined in the past, was 22% manganese and 36% iron (dry basis). Some high-grade manganese dioxide (up to 90%) was mined. It occurs as small pockets in the lower-grade ore. Production averaged 3,800 m.t. per year from 1968 to 1976, when military activities forced the closure of the operation. The percentage of each ore type that this production represented is unknown. Reserves are believed to be limited. Egypt is not listed in Resource Tables 3-7 or 3-8.

REFERENCES

Gill, D. and Ford, S.O., Manganiferous Iron Ore Deposits of the Um Bogma District, Sinai District, Egypt, Symposium on Manganese Deposits, Vol. II, Africa, XXth International Geological Congress, Mexico, pp. 173-177, 1956.

Margaritz, M. and Brenner, I.B., The Geochemistry of a Lenticular Manganese Ore Deposit (Um Bogma, Southern Sinai), Mineralium Deposita 14, pp. 1-13, 1979.

Mart, J. and Sass, E., Geology and Origin of the Manganese Ore of the Um Bogma, Sinai, Economic Geology 67, pp. 145-155, 1972.

U.S. Bureau of Mines, Minerals Yearbooks, U. S. Government Printing Office, Washington, D. C., 1955-1976.

B.21 IVORY COAST

There has been no recorded production of manganese ore since 1970 when the Grand Lahou Mine, located about 100 km west of Abidjan and operated by Mokta, was closed due to the exhaustion of the reserves.

A number of small resources have been outlined by the Bureau de Recherches Geologiques et Minieres (W. A. Preston, British Steel Corporation, presentation to the Committee, August, 1979). Three northern deposits, including Odienne and Ziemougoula, occur in gondite or weathered gondite in the Upper Birrimian of Proterozoic age. In the Ziemougoula deposit, located about 300 km northwest of Abidjan, 80% of the mineralization is reported to be made up of pseudo-ramsdellite or battery-grade manganese oxide of Nsuta-type. One deposit is considered to contain 5 to 6 million m.t. at 25 to 30% manganese and the other two about 2 to 3 million m.t. at 20 to 30% manganese. The deposits have only been outlined by regional mapping.

In the Man Area, itabirite occurrences containing 20 to 25% manganese and 25 to 30% iron have been discovered during regional mapping programs (Preston, 1979). The northern and Man Area deposits are considered to be submarginal resources with limited tonnage potential.

REFERENCE

U.S. Bureau of Mines, Minerals Yearbooks, U. S. Government Printing Office, Washington, D. C., 1964.

B.22 MALI

Two deposits, Takavasita and Ofolikine, have been discovered in the southern part of Mali, southeast of Ansongo and near the border of Upper Volta. Lack of transportation and infrastructure have precluded more than initial exploration of these deposits.

The Takavasita deposit is situated in prominent hills within an extensive peneplane. The manganiferous quartzite beds are steeply dipping and strike about 3 km. They are at the base of the Ansongo Series within a quartzite sequence and have been metamorphosed to gondite. Psilomelane and pyrolusite occur as superficially enriched cappings and as concretionary masses on the surface. The submarginal resource is reported at 7.7 million m.t., with a grade of 43 to 47% Mn, 1 to 4% Fe, 3 to 4% SiO_2, 0.015 to 0.25% P and a little barite.

The Ofolikine deposit (W. A. Preston, British Steel Corporation, presentation to the Committee, 1979) is located to the east of Ansongo. It is reported to have a grade of 35 to 40% manganese and could occur over a 10 km strike length in an intercalated sequence of clayey schists within the Ansongo Series.

REFERENCE

Servant, J., Les Gisements et Indices de Manganese de l'Afrique Occidentale Francaise, Symposium on Manganese Deposits, Vol. II, Africa, Ed. J.G. Reyna, XXth International Geological Congress, Mexico, pp. 89-98, 1956.

B.23 NAMIBIA

Production of manganese ore from the Otjonsondu deposits has been intermittent since 1939. There has been no production since 1966 when 22,830 m.t. were produced by open-pit methods at an estimated grade of 45+% manganese. The deposits are in northeast Namibia about 185 km northeast of Windhoek.

The Otjonsondu manganese bodies (Roper, 1956) are associated with a thin, highly metamorphosed iron bed, itabirite, within quartzites of the Precambrian Damara System. The sediments are highly folded. The mineralization occurs at three horizons, one immediately below the itabirite, the second within the itabirite, and the third at the upper contact. The itabirite zone is 100 to 150 m thick.

The mineralization is found in lenses from 2 to more than 7 m in thickness, averaging about 5 m. The lenses are lenticular along strike and individual lenses are up to 1,700 m long. The thicker central portion of the lenses are often higher in grade than the edges. The hanging-wall ore bodies are usually of higher grade than those nearer the footwall. The chief ore minerals (De Villiers, 1951) are braunite, jacobsite, hausmannite, bixbyite, and hollandite. Supergene enrichment is insignificant.

The reserves in 1956 were given as 3.7 million m.t. at a grade of 40 to 48+% manganese and should be considered as submarginal. The reserves may have extensions with depth, but could only be exploited by underground mining.

REFERENCES

De Villiers, J.E., The Manganese Ores of Otjonsondu, South West Africa, Transactions, Geological Society of South Africa, pp. 89-98, 1951.

Roper, A., The Manganese Deposits at Otjonsondu, South West Africa, Symposium on Manganese Deposits, Vol. II, Africa, XXth International Geological Congress, Mexico, pp. 115-112, 1956.

U.S. Bureau of Mines, Minerals Yearbooks, U. S. Government Printing Office, Washington, D. C., 1967.

B.24 NIGERIA

Gondite deposits occur in the northern part of Nigeria and have been explored only by reconnaissance mapping and sampling. It is considered that a number of deposits may occur over a wide metasedimentary belt with spessartite-rich schists. Only 5,000 to 10,000 m.t. of recoverable material at 25% manganese have been suggested (W. A. Preston, British Steel Corporation, presentation to the Committee, 1979). It is doubtful, unless manganese oxide deposits occur, that the silicate occurrences will be of any consequence. Nigeria is not listed in the Resource Tables 3-7 or 3-8.

B.25 SUDAN

There has been intermittent production of manganese ore from the Red Sea area. The last recorded production was during the years 1962 to 1970, when an estimated 21,600 m.t. were produced at a grade of 36 to 44% manganese.

Manganese deposits or occurrences are found at several places in the Red Sea Hills, the Red Sea coast, and around Paloich-Wabuit in the Upper Nile Province of southern Sudan. Several deposits were exploited in the 1950's in the southern Red Sea Hills and were rapidly exhausted. The deposits on the coastal strip had a small scale, spasmodic production. The deposits were worked by primitive methods and hand sorted to separate the manganese from the iron mineralization.

The Abu Samr, Talik, Allaikalieb deposits in the southern Red Sea Hills are vein-like deposits. They are associated with gondite, containing spessartite, rhodonite, braunite, and minor rhodochrosite, that is interbedded with various schists, gneisses, and quartzites. The deposits are supergene and have been concentrated and enriched along fractures and fault zones. The veins vary in width from 30 cm to 2.5 m, have maximum lengths of 270 m, and rarely extend in depth more than 12 to 15 m. The manganese mineralization, consisting of psilomelane and pyrolusite with minor manganite, is associated with magnetite and hematite. It ranges in grade from 7% manganese with 44% iron to a maximum of about 51% manganese and 4% iron and averages 27% manganese. The silica content varies from 1 to 44%. The deposit at Sinkat in the central Red Sea Hills is a similar supergene, vein-like deposit with a grade of 47 to 55% manganese.

In the coastal Red Sea area the deposits are concentrated in the vicinity of Halaib. The manganese mineralization, pyrolusite, psilomelane, and manganite together with hematite, is found either in veins occupying fault planes or as concretionary patches that occasionally form the cementing material of a conglomerate. The veins are 1.25 to 2 m thick and up to 200 m long. The mineralization grades from 23 to 53% Mn, 1.4 to 3.5% Fe, and 3 to 54% SiO_2.

Manganiferous iron formation was found in the Paloich-Wabuit area, in the Upper Nile Province, in unconsolidated and clayey sands of the Umn Ruwaba Series of post-mid Tertiary age, with the manganese in the form of wad. The manganiferous iron formations occur at several horizons with a maximum thickness of 4 m and depth to 145 m. The mineralization grades between 1.7% manganese and 55% iron to 23% manganese and 26.8% iron.

The reserves of the deposits in the Red Sea area have been largely depleted and the resources are presumed to be negligible. Sudan is not listed in the Resource Tables 3-7 or 3-8.

REFERENCES

Kabesh, M.L. and Atia, M.S., Manganese Ore Deposits of the Sudan, Bulletin No. 9, Geological Survey Department, Sudan, 1961.

U.S. Bureau of Mines, Minerals Yearbooks, U. S. Government Printing Office, Washington, D. C., 1960-1976.

B.26 ZAMBIA

Most of the manganese deposits in Zambia occur in the Fort Rosebery district, 145 km north of Broken Hill, and the Kampumba an Chiwefwe occurrences northeast and southeast of Broken Hill. There was a modest production of high-grade ore (50 to 56% manganese) from the early 1950's until 1969. This was the last year of recorded production, when 25,455 m.t. of ore were produced. The peak occurred in 1962 with the production of 57,088 m.t.

In the Fort Rosebery district, 25 deposits have been discovered in an area over 36 km long. The greater part of the area is underlain by a pink granite intrusive into quartz porphyries. It contains several minor faults striking approximately north-south, parallel to the Luapula Rift. Brecciated quartz porphyry or silicified breccia are occasionally along the strike of the faults. The ore deposits that are considered to be a replacement of the country rock and breccia along the fault planes are aligned north-south, almost vertically. They pinch and swell from a few centimeters to three or four meters and extend horizontally from a few meters to hundreds of meters along strike. The average width is slightly less than one meter. The bulk of the ore consisted of psilomelane with minor hausmannite, and manganite with some pyrolusite in cavities. The bodies, which rarely extend below 50 m had an average grade of 52 to 56% Mn, 0.5 to 2.0% Fe, 2.5 to 10% SiO_2, and 0.01 to 0.06% P.

The Kampumba deposits are in a group of hills that are capped by iron and manganese mineralization. Rhodochrosite-bearing dolomite occur as lenses in a series of schists, and it is thought that the manganese and the iron replaced both the dolomite and the schists during weathering as a supergene enrichment process, the iron being produced from the schists. The deposits are massive bodies or rubble deposits mainly along the slopes of the hills. The solid bodies of manganese mineralization, with veinlets of hematite, are in cliffs five to six meters high and can be traced for several hundred meters. The deposits are shallow in depth and at a certain depth grade into wad. The rubble deposits consist of lumps and boulders of hematite with some manganese mineralization. The manganese ore was hand-sorted both from the solid and rubble deposits. The manganese mineralization is predominantly psilomelane, with hausmannite and braunite. Ore grading 50 to 57% manganese was produced.

The Chiwefwe deposits occur in several sheet-like rubble bodies that lie on top of phyllite, schists, and brecciated quartzites. Quartzite and conglomerate breccia were replaced by manganese oxide, with the manganese being leached from the phyllites and shaly sandstones.

It is presumed that the reserves have been largely depleted and that any resource would be minimal, as the known deposits had limited persistence. It was announced in 1977 that the Luwana mine near Mansa in the Fort Rosebery district was to be reopened and produce battery-grade ore from a total reserve of 30,000 m.t. at a rate of 770 tons per year.

REFERENCES

Fockema, R.A.P. and Austen, A.L.S., Manganese Deposits of Northern Rhodesia, Symposium on Manganese Deposits, Vol. II, Africa, XXth International Geological Congress, Mexico, pp. 273-291, 1956.

Mining Magazine, 137, 301, (News item, untitled.), April 1977.

U.S. Bureau of Mines, Minerals Yearbooks, U. S. Government Printing Office, Washington, D. C., 1960-1970.

B.27 ZIMBABWE

Manganese occurrences in Zimbabwe are widespread and are present in many rock types, such as limestone and dolomite, that may contain small amounts of mineralization, sometimes as small veinlets. The known occurrences are all small and it is presumed that this type of resource is inconsequential. The most extensive deposits are those associated with iron formation and the resource of manganiferous iron ores may be considerable. The most important bodies are in the Que Que area in the central part of the country, where blobs and patches of manganese oxides occur in hematite. Composition is very variable, ranging from as much as 2 to 24% manganese in the Que Que iron ores. It would appear that production of 29% grade ore has been in the Sinoia district by and for the use of Rhodesian Iron and Steel Company Ltd. In 1962, over 7,000 m.t. were produced, but in 1965 only 417 m.t. were produced. Zimbabwe is not listed in the Resource Tables 3-7 or 3-8.

REFERENCES

Anderson, R.B., A Handbook of Useful Information Regarding Base Minerals, Mines Department Bulletin, No. 6, Southern Rhodesia, Salisbury, pp. 43-45, 1962.

The British Sulphur Corporation, Ltd., Rhodesia, A Special Survey of The Mining Industry, The British Sulphur Corporation, Ltd., London, p. 37, 1972

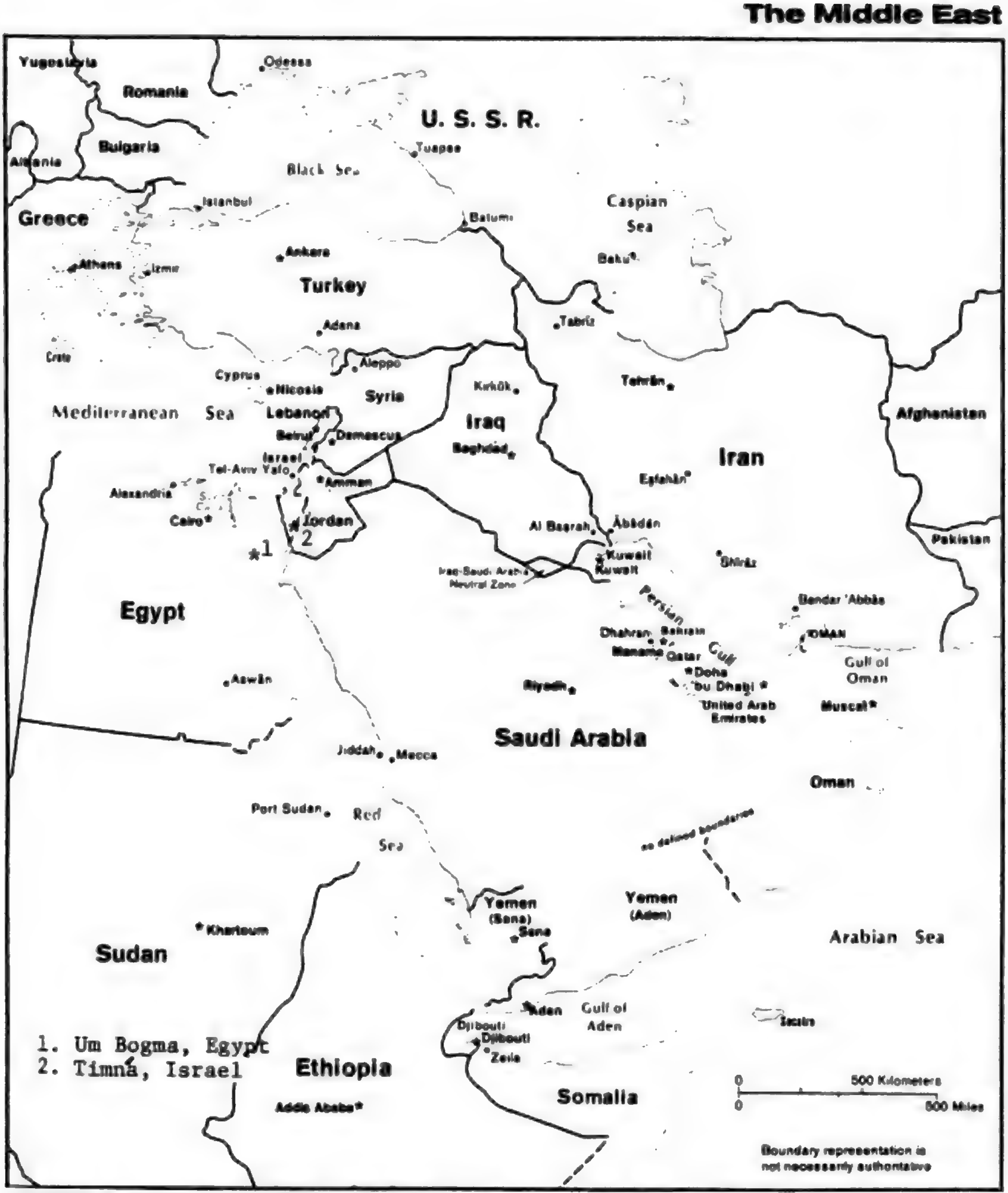


FIGURE B-3. Potential Mines in Egypt (Sinai) and Israel

ASIA

B.28 BURMA

Burma has been a very small producer of manganese on an intermittent basis. In the five year period 1970 to 1975, a total of 1,053 m.t. were produced and this after a lapse of six years.

There are no manganese deposits of consequence in Burma. Nodular and concretionary manganese is frequently associated with ferruginous concretions in the Irrawaddian Series, the iron ore of the Myingyan District (Southern Shan States) and in the Nawngthakaw residual hematite area on limestone, of low potential (latitude 22°-10' north and longitude 96°-31' east). The manganese concretions are not considered even a submarginal resource because of the small potential of the iron ores with which they are associated in sandstone in the Irrawaddy and Pegu Series of Pliocene and Oligocene Age respectively. While the Oligocene has been the most productive manganese epoch in other parts of the world (Ukraine, Caucasus, etc.), the Burmese lithology, with rapid sedimentation changes, does not favor the conditions necessary for manganese deposition. Burma is not listed in the Resources Tables 3-7 or 3-8.

BIBLIOGRAPHY

Chhibber, H.L., Geology of Burma, MacMillan and Co., New York, 1934.

Chhibber, H.L., The Mineral Resources of Burma, MacMillan and Co., New York, 1934.

U.S. Bureau of Mines, Minerals Yearbooks: Vol. 1, U. S. Government Printing Office, Washington, D. C., 1963-1977.

B.29 INDONESIA

The manganese deposits in west and central Java, principally those in the Karangnunggal area in the southern mountains south of Tasikmalaja and in the Kliripan area in the West Progo Mountains, are mostly very small, mined both by open-pit and underground methods, and are labor-intensive. The better deposits have been exhausted. The deposits are irregular lenticular bodies occurring in or on top of volcanic tuffs and breccias of Lower or Middle Miocene age that are overlain unconformably by reef limestone. At the plane of unconformity, the manganese is found as pockets and lenses up to 4 m thick, a maximum length of 500 m, and a width of 100 to 200 m and are also found as impregnations in the overlying limestone. The ore minerals are pyrolusite, psilomelane, and wad. Some of the crystalline pyrolusite also occurs as concretions. Manganese also is found as concretions on the surface of the lateritic soil and is ferruginous, as stringers and fracture-fillings on the lateritic profile and as vein fillings in reef limestone.

The reserves are small. In 1969, the reserves at Kliripan were estimated at 130,000 tons averaging 30% manganese, and at Karangnunggal as 350,000 tons averaging 28% manganese. These should be classified as a resource.

The manganese production varies from year to year. The total ore production from 1968 to 1977 is about 102,490 m.t. Almost the entire production is high-grade MnO_2 ore, either battery-grade or chemical-grade. The reported 1977 manganese ore production, 5,974 m.t., had an average MnO_2 content of 87.7%. Most of the production is thought to have been exported to Japan and Taiwan, with the rest used domestically to produce dry-cell batteries.

REFERENCES

Sigit, S., Purbo-Hadiwidjojo, M.M., Sulasmoro, B., and Wirjosudjono, A., Minerals and Mining in Indonesia, Ministry of Mines, Djakarta, pp. 61-65, 1969

U.S. Bureau of Mines, Minerals Yearbooks: Vol. 1--Metals, Minerals and Fuels, U. S. Government Printing Office, Washington, D. C., 1969-1977.

Van Bemmelen, R.W., The Geology of Indonesia (1949/1970), Economic Geology, II (1970), 139-146. Special edition of the Bureau of Mines in Indonesia, Martinus Nijhoff, (Originally published 1949, reprint 1970.), The Hague, 1970.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books Ltd., Garden City Press Ltd., 1977.

B.30 IRAN

The production of manganese ore was reported as 40,000 m.t. in 1977, with an estimated grade of 33+% manganese. This is an increase from a production low of 4,988 m.t. in the years 1971 to 1973.

Three hydrothermal lenses in lower Tertiary andesite have been or are being exploited. These are the Rabat-Karim, Shah-Rokh, and Boz Nein deposits located in north-central Iran, to the southwest and southeast of Tehran. The Rabat-Karin, which is probably depleted, was a lens of pyrolusite 8 m thick and 120 m long. Shah-Rokh ore consists of pyrolusite mixed with hematite and magnetite. The run-of-mine ore contains 32 to 34% manganese that can be upgraded to 38 to 40% manganese by hand-sorting and screening. At Boz Nein (Gibson, 1956), massive manganite with pyrolusite and minor rhodochrosite and rhodonite occur in a sheer zone with an average width of 5 m. Laterally to 10 m the mineralization occurs as veinlets, disseminations, and replacement masses. It is considered that the oxide was produced by the alteration of rhodochrosite and possibly rhodonite.

The reserve of the manganese ore is thought to be small and it is considered that any extensions will be limited. There is a small, submarginal resource of about 70,000 tons of manganese ore associated with pillow lavas in a volcanosedimentary sequence in the area of Sabsewar in northern Iran. The mineralization has a high silica content. The deposit at AB-Band in southern Iran is thought to be a localized occurrence in radiolarite and connected with submarine volcanic activity (Walterns and Etminan, 1973).

Iran is not listed in Resource Tables 3-7 or 3-8.

REFERENCES

Bariand, P., Issakhanian, V., and Sadrzadeh, M., Preliminary Metallogenic Map of Iron, Report No. 7, Geological Survey of Iran, p. 13, 1965.

Gibson, R., Memoranda Reports on Geologic Spot Examinations of Mines and Prospects in Iran, February 1954 through June 1955, U.S. Geological Survey Open File Report No. 397, 1956.

Ladame, G., Les Ressources Metalliferes de l'Iran, Schweizerische Mineralogische and Petrographische Mitteilugen, 25/1, p. 267, 1945.

U.S. Bureau of Mines, Minerals Yearbooks, Vol. 1--Metals, Minerals and Fuels, U. S. Government Printing Office, Washington, D. C., 1972, 1977.

Walters, W.A. and Etminan, H., Manganese in Iran, Report No. 21, Geological Survey of Iran, pp. 37-52, 1973.

B.31 ISRAEL

The Timná (Menaiye) deposit is situated on the western edge of the Arave Rift Valley, 25 km north of the Red Sea port of Eilat. Regionally, the basement rocks consist primarily of granite, syenite, and monzonite. They are overlain unconformably by a series of flat-lying terrestrial sandstones and marine shales, dolomite, limestones, and dolomitic sandstones. Manganese oxide is confined to two units of Silurian age within this sequence that are termed the "Zebra Sandstone" and the "Upper Shale."

The mineralization has four modes of occurrence. The most important is the concretionary manganese ore that has been found mainly at a locality called Manganese Hill. Most of the concretions occur in the upper 0.5 to 1.5 m of the Upper Shale. The total thickness of the Upper Shale is 3 m or less. The shale is highly contorted and brecciated. The concretions range in diameter from 1 mm to about 50 cm and are irregular in shape. The concentration of the nodules is variable and represents from 20 to 80% of the volume. The concretions contain 58.3% to 75.1% MnO_2, 1.6 to 4.4% MnO, 1.6 to 13.4% SiO_2, 2.65 to 4.18% Fe_2O_3, up to 0.93% PbO, 1.29% CuO, and 0.38% P_2O_5. Finely divided manganese oxide disseminated in the Zebra Sandstone or the overlying Upper Shale is widespread. A partial analysis of silty shales shows 36.2% MnO_2, 34.1% SiO_2, 9.0% Al_2O_3, 4.1% Fe_2O_3, 0.3% CuO, and 1.2% P_2O_5.
Laminae less than 1 mm in thickness in the Zebra Sandstone are alternately manganese-bearing and manganese-poor to manganese-free. Manganiferous veins occur, rarely, in the Upper Shales. The manganese mineral in the disseminated deposits, as well as in the laminae, is mainly fine, powdery pyrolusite, while the concretions are formed by pyrolusite, psilomelane, and possibly ramsdellite.

The resources of the disseminated manganese available to open-pit mining have been estimated at 10 million m.t. at a grade of about 23% manganese. The amount of concretionary material is estimated at 560,000 m.t. This is a submarginal resource in that not only does the material have a relatively low manganese content, but it also has a poor manganese-to-iron ratio and a high percentage of lead and copper contaminants.

REFERENCE

Bentor, Y.K., The Manganese Occurrences at Timná (Southern Israel), A Lagoonal Deposit, Symposium on Manganese Deposits, Vol. IV, Asia and Oceana, XXth International Geological Congress, Mexico, pp. 159-172, 1956.

B.32 REPUBLIC OF KOREA

The manganese ore production, although continuous for the last 20 years, has never been large. The maximum production was achieved in 1967 when 7,184 m.t. were produced. The average annual production for the ten year period 1968 to 1977 is 2,363 m.t. at an estimated grade of 35 to 40% manganese.

The manganese deposits, which are all small and mined by discontinuous operations, are mainly located in the southeastern and central parts of the Korean peninsula in ten districts (Kim and Kim, 1971). They are generally developed in dolostone and limestone of Precambrian or Palaozoic formations, rhyolite and andesite flows, and partly in granite, phyllite, or shale. The deposits may be classified into hydrothermal replacement deposits, veins, or sedimentary, residual, or metamorphic deposits and consist of manganese carbonate, oxide, and silicate minerals. The psilomelane-type oxides occur as oxidation cappings above rhodochrosite.

The Samham-Janggun deposit in the east-central area was regarded as one of the larger manganese mines in the Republic. It is a contact metamorphic deposit in limestone intruded by granite. The ore, mined by open-pit, consisted of an oxidized upper portion and a lower portion of stringers of rhodochrosite along bedding planes in the limestone. The grade of the oxides averaged 30 to 35% manganese with a maximum of 45%. The carbonate averaged 30 to 35% manganese.

The manganese reserves and resources in the Republic of Korea are presumed to be small. The resources in three of the ten districts in 1968 were given as 750,000 m.t. Korea is not listed in the Resource Tables 3-7 or 3-8.

REFERENCES

Gallagher, D., Mineral Resources of Korea, Vol. VIB, Non-Metallics and Miscellaneous Metals, Industry and Mining Division, USOM/Korea, in cooperation with Geological Survey, Republic of Korea, pp. 99-102, 1963.

Hwang, I.C., Report on the Sam Han Chang Gun Manganese Deposits, Journal of the Korean Institute of Mining Geology (Korean English Summary) 1/1, pp. 9-34, 1968.

Kim, S.J. and Kim, G.S., Manganese Deposits of South Korea (Preliminary Report). Bulletin No. 13, Geological Survey of Korea, pp. 369-407, 1971.

U.S. Bureau of Mines, Minerals Yearbooks, U. S. Government Printing Office, Washington, D. C., 1961-1977.

B.33 MALAYSIA

There has been no confirmed production of manganese ore from Malaysia since 1969 when 10,200 m.t. of an estimated grade of 30 to 40% Mn were produced. Production has been reported every year since 1969, but is believed to be ferruginous manganese ore. Manganese ore occurred in the northeastern part of the country in the states of Trengganu and Kelantan. Secondary oxides, pyrolusite, and psilomelane occur in small masses, nodules or pellets, in the laterite or in veinlets in the underlying weathered rock. Most of the ore occurred in cavernous masses underlying a bouldery surface layer of detrital ore. The resource potential is presumed to be very small. Malaysia is not listed in the Resource Tables 3-7 or 3-8.

BIBLIOGRAPHY

Savage, H.E.F., A Note on Manganese in Malaya, Symposium on Manganese Deposits, Vol. IV, Asia and Oceania, XXth International Geological Congress, Mexico, 1956.

U.S. Bureau of Mines, Minerals Yearbook, Vol. 1--Metals, Minerals and Fuels, U. S. Government Printing Office, Washington, D. C., 1970.

B.34 PAKISTAN

Principal occurrences studied are in the Las Bela District, about 100 km northwest of Karachi or 75 km north of the coast. Location is favorable for export, were there any tonnage. Occurrences are of the volcanogene type and thus of small potential. Manganese oxides occur at the contact of pillow lavas and Cretaceous shales. Thickness rarely exceeds one meter and there is little continuity. Manganese also occurs as fracture fillings and veinlets. There is no carbonate protore. Ore has 20 to 44% Mn and 12 to 30% SiO_2. Total indicated reserves are about 30,000 tons in scattered localities. Since manganese has been known in the area since 1904, prospects for important discoveries seem slim. Pakistan is not listed in the Resource Tables 3-7 or 3-8.

REFERENCE

Ali, S.I., A Study of Manganese Ore Deposits, Las Bela, West Pakistan, Acta Mineralogica-Petrographica, Szeged XX/1, pp.141-148, 1971.

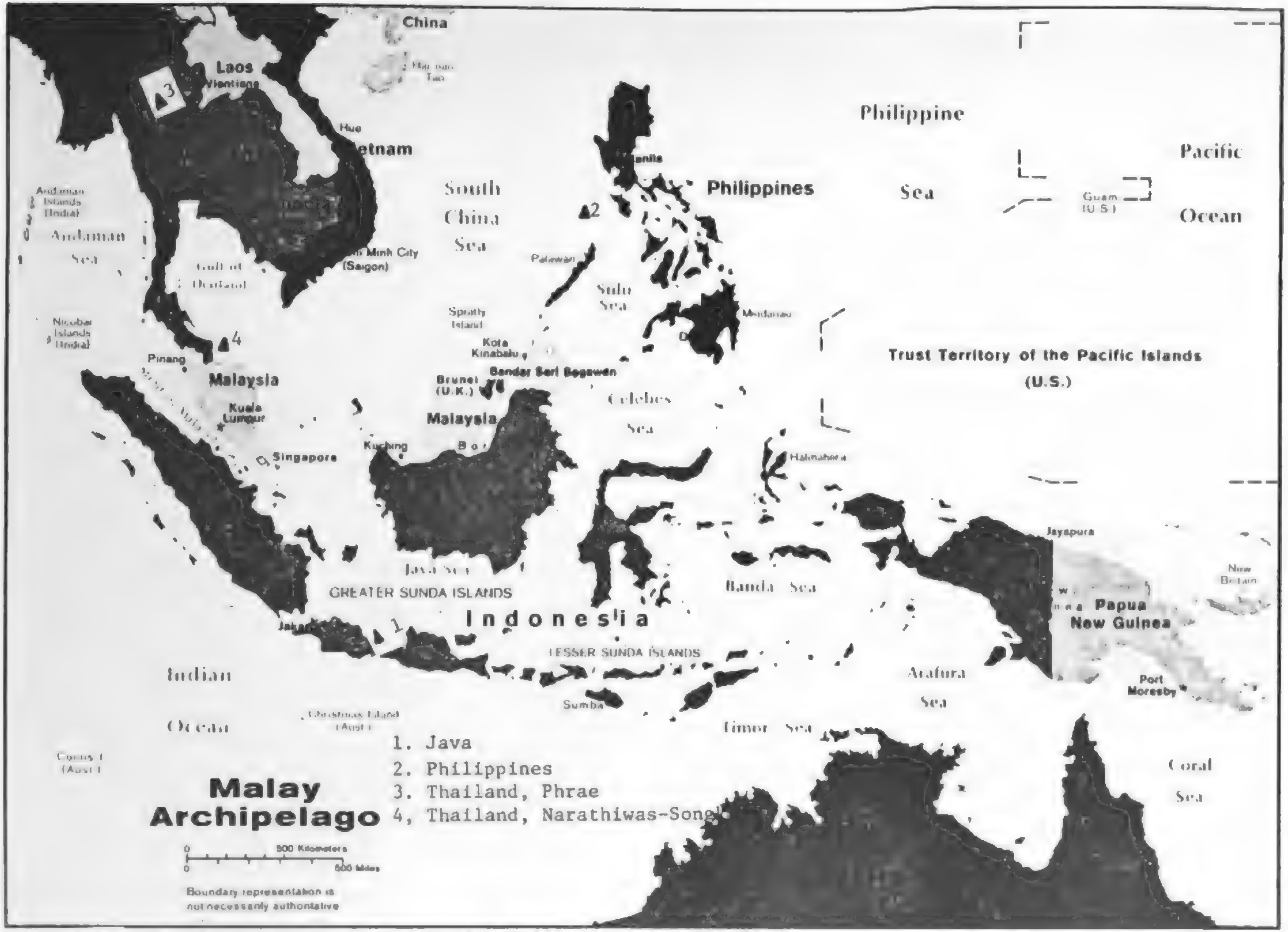


FIGURE B-4. Producing Areas in Indonesia, Philippings and Thailand

B.35 PHILIPPINES

The Philippines have been a persistent but relatively small producer of manganese, at a varying yearly rate. Within the period 1960 to 1977, the peak production was in 1967 when 85,800 m.t. were produced. This was followed by a rapid decline to no production reported in 1975. The estimated production in 1977 was reported as 20,435 m.t. with an estimated grade of 44+% manganese. The total production since 1960 has been 390,000 m.t.

The manganese deposits (Oiwa, 1961) are widely scattered throughout the islands and generally are not very large. The largest producers are on the island of Busuanga and in the province of Ilocosnorte. Busuanga manganese ore has a high (about 50%) manganese content and a low iron and phosphorus content. The ore chiefly occurs as massive, lump psilomelane with a minimum of fines. It is mined mainly by open cuts and hand sorted before shipping.

The deposits in Busuanga Island are primary sedimentary deposits in which manganese lenses 2 to 8 m thick are interbedded with quartzite and/or jasper. Manganese also occurs as concentrations near intersections of small quartz veins or as irregular kidney-shaped masses. Large boulders of manganese are frequently on the surface over or adjacent to the lenses. The quartzite is strongly folded, with the manganese frequently faulted and often displaced. The continuity of the lenses is interrupted, which often limits their extent both laterally and vertically. Therefore, it is not expected that the individual lenses of manganese will be of large tonnage or great extent.

The reserves as of 1961 were variously estimated at 6 million m.t. or more. There are some marginal deposits that are operated economically only during periods of market demand. It is considered that the potential for developing further reserves is good, but it is presumed that they will not be large.

REFERENCES

Division of Geology, The Mineral Resources of the Philippines for the Years 1934-1938, Part II -- Base Metals and Nonmetallics, Philippines, Bureau of Mines, pp. 67-95, 1940.

Oiwa, Y., Nordquist, C.G., and Lentz, O.H., The Mineral Industry of Japan and Southeast Asia, Quarterly of the Colorado School of Mines 56/4,pp. 216-217, 1961.

U.S. Bureau of Mines, Minerals Yearbook, Vol. 1--Metals, Minerals and Fuels, U. S. Government Printing Office, Washington, D. C., 1977.

Weiss, S.A., Manganese, The Other Uses, Metal Bulletin Books Ltd., Garden City Press Led., Hertfordshire, U. K., 1977.

B.36 THAILAND

Manganese deposits occur in many parts of Thailand. In the north, Lamphun Province (Industrial Minerals, 1977) is the largest producer of metallurgical-grade manganese with 11,087 and 13,073 m.t. produced in 1974 and 1975 respectively. Phetchabun and Phrae Provinces are modest producers of battery- and metallurgical-grades; Chiang Rai, Nan, Lampang, and Sukothai Provinces produce battery-grade; and Chaing Mai and Uthai Thani produce only metallurgical-grades. Rayong Province in the central area and Loei Province in the east produce battery-grade ore. In the southern area, Narathiwat Yala and Songkala Provinces produce metallurgical-grade. The total manganese ore production, which varies greatly from year to year, was 24,914 m.t. in 1975, of which 20,493 tons was metallurgical, 3,577 tons battery and 844 tons chemical. The preliminary ore production reported for 1977 was 76,946 m.t. at an estimated grade of 46 to 50% manganese.

Most of the manganese deposits in northern Thailand consist of compact surficial accumulations of granules, pellets, pebbles, lumps, and nodules of psilomelane and pyrolusite in lateritized overburden, or in the form of pods, impregnations, and fracture-fillings in brecciated or porous rocks. Locally manganese oxide and rhodochrosite form narrow veins. The deposits, formed by local deposition and enrichment by leaching, are generally located at the base of fairly steep slopes along the sides of valleys. They are mined both by manual labor or by power shovels, from simple open pits or trenches, and trucked to a mill. The average grade of the in-place ore is fairly low (40 to 50% MnO_2) but is upgraded by washing, scrubbing, screen-sizing, hand sorting, and in some cases by additional crushings and a second sorting.

The reserves of manganese ore are small. In 1965 it was reported (Gardiner et al., 1965) that the reserves in 8 or more deposits in northwest Thailand could be as much as 3 million tons, with grades of 5 to 65% MnO_2. The grades indicate that a portion of the reserves were actually submarginal and paramarginal resources. The possibility of finding other deposits of similar size is considered to be good; however, it is not expected that a large reserve will be developed. Thailand is not listed in Tables 3-7 or 3-8.

REFERENCES

Beall, J.V., Thailand, Mining Engineering 22/7, p. 105, July 1970.

Gardner, L.S., Damrongmanee, T., and Smith, R.M., The Ban Mae Jong and Other Manganese Deposits in Northwestern Thailand, Report of Investigation No. 8, Thailand Department of Mineral Resources, 1965.

Industrial Minerals, The Industrial Minerals of Thailand, No. 117, pp. 35-36, June 1977.

Jacobson, A.S., Pierson, C.T., Danusawad, T., Japakaseter, T., Inthuputi, B., Siriratanamongkal, C., Prapassornkul, S., and Pholphan, N., Mineral Investigations in Northeastern Thailand, Professional Paper 618, U. S. Geological Survey, Washington, D. C., pp. 13-18, 58-63, 1969.

U.S. Bureau of Mines, Minerals Yearbook, Vol. 1--Metals, Minerals and Fuels, U. S. Government Printing Office, Washington, D. C., 1977.

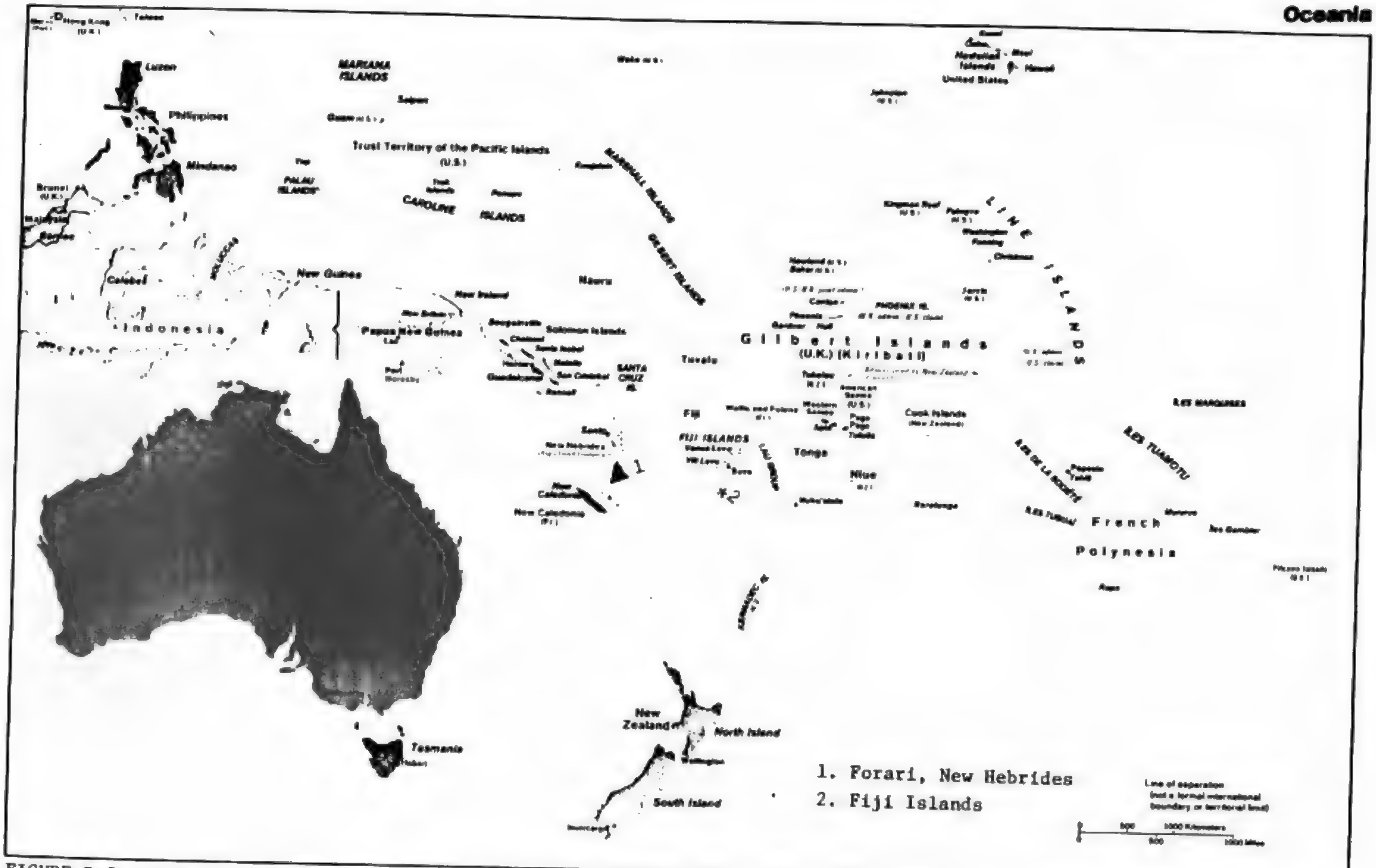


FIGURE B-5. Potential Mines in the Fiji Islands, and Producing Mines in the New Hebrides

OCEANIA

B.37 FIJI

The manganese ore production by Fiji has been variable yearly and it has no recorded production since 1971 when 7,596 m.t. were produced. The production in the previous year was 24,349 m.t. at an estimated grade of 30 to 50% manganese.

The Fiji manganese deposits, found mainly on the island of Viti Levu, are small. The deposits consist of manganese oxides, pyrolusite and psilomelane, with lesser amounts of braunite, hausmannite, and possibly bixbyite. The oxides are intimately associated with a brownish-red jasper that commonly envelopes the oxides. The mineralization occurs along brecciated zones in faults and fractures and selectively replaces the tuff, limestone, sandstone or mudstone, and occasionally volcanic wallrock. The deposits tend to be irregular replacement bodies and occur vertically as elongated lenses, tabular bodies, or irregular masses. The mineralization grades from a relatively massive center into the enclosing rock through a zone containing veinlets, stringers, and irregular pods of manganese. The high-grade mineralization ranges from 45 to 60% manganese and averages about 52% manganese. The low-grade, containing up to 25% silica, includes numerous lenses and irregular patches of limonitic jasper. Mining was by open-pit with the ore hand-sorted. Several of the mines closed because of an excessive strip ratio.

The resource estimate (W. A. Preston, British Steel Corporation, presentation to the panel, 1979) is 310,000 m.t. of mineralization at 72 to 95% MnO_2, of which 100,000 m.t. are categorized as measured, and 1.365 million m.t. of siliceous ore, of which 585,000 m.t. are measured.

REFERENCES

Band, R.B., Vunamoli Manganese Mine Diamond Drilling 1962-1963, Economic Investigations No. 3, Geologic Survey of Fiji, Government Press, Suva, Fiji, 1965.

Harvey, S.R.M., Geology and Mining of Manganiferous Deposits of Nasaucoko, Colowest Viti Levu, Report No. 50, Geological Survey Department of Fiji, Report No. 50, Suva, Fiji, 1958.

Hautz, R.E., and Phillips, K.A., Interim Report on the Economic Geology of Fiji, Economic Report No. 1, Geological Survey Department of Fiji, Government Press, Suva, Fiji, 1963

Skiba, W.J., Geological Studies in Southwest Viti Levu, Memoir 1, Geological Survey Department of Fiji, Government Press, Suva, Fiji, 1964.

U.S. Bureau of Mines, Minerals Yearbook, Vol. 1--Metals, Minerals and Fuels, U. S. Government Printing Office, Washington, D. C., 1977.

B.38 NEW HEBRIDES CONDOMINIUM (VANUEVA*)

The only commercial manganese ore production has come from the Forari deposits on Efate Island (Capital-Port Vila) at 168° E and 16° S. Le Manganese de Vate, owned 87.5% by Southland Mining Ltd. of Sydney, Australia, has mined small orebodies sporadically for over ten years. Production reached a high of 79,700 m.t. in 1967 and has declined to 24,521 m.t. in 1977. Mn oxides occur as a nearly horizontal bed 0.6 to 0.3 m thick, overlain by 1 to 6 m of tuffs and clay which is stripped. Crude ore grading about 30% manganese is washed to remove coral and clay, raising concentrate grade to about 41 to 42% manganese. Manganese to iron ratio is about 9 to 1, P about 0.1%, TiO_2 0.5%, SiO_2 10%, BaO up to 2%, and Al_2O_3 about 8%. The principal mineral appears to be todorokite, but alkalies are moderate.

Most of the New Hebrides occurrences are residually enriched accumulations of manganese oxides in calcarenites, the manganese having been derived from basic volcanic pyroclastics by laterization. Deposits of this genesis are invariably small, the largest rarely exceeding a million tons potential and most being very much smaller.

Original Forari reserves were 1.6 million m.t. Preston (private communication to the panel, 1979) gives Forari reserves at 270,000 m.t. of 42% manganese, while another source suggests the reserves will be exhausted by 1980. In any case, the potential is small. Resources consist of tailings dumped in a nearby bay, but potential has no significance.

The Geological Survey prospected for analogous Mn on Epi Island and found none. South Malekula Island was also examined and Mn-oxide veinlets only a few cm thick, grading 16% to 17% manganese, have no potential. Mn occurrences of no significance are also known on Torres, Hui, Maewo, Espirito Santo, and Tanna Islands.

Erromango Island was intensively studied by the French State Geological Bureau in 1959 for lagoonal-reef-type manganese-oxide deposits derived from volcanics. After a campaign of auger drilling, several lenses up to 4 to 6 m thick and 150 to 600 m long were found. Manganese ranged from 4 to 15% (in clay) or 40 to 45% in powdery ore, with high phosphorus ranging from 0.17 to 1.2%. Oxides are pyrolusite and todorokite. Tonnage in aggregate may be 1.6 million m.t., but is insignificant, including resource potential, because of scattered distribution. Likewise, residual accumulations in limestone on Erromango have 20% manganese, while tuffs have 45% manganese. None is more than 3 m thick and potential is insignificant.

The genetic type of occurrence, limited by the particular geology of the New Hebrides, limits manganese-oxide potential to a relatively insignificant amount when considering the world.

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*In July, 1980, Vanueva became the new name of the island group.

REFERENCES

de la Rue, A., La Manganese aux Nouvelles Hebrides, Symposium on Manganese Deposits, Tomo Iv, Asia y Oceania, XXth International Geological Congress, Mexico, pp. 331-332, 1956.

Lemaire, B., Etude Geologique de l'Ile d'Erromango, Bureau de Recherches Geologique et Minieres (BRGM), Memoir No. 38, 1965.

Mallick, D.I.J., Annual Report of the Geological Survey, New Hebrides Condominium, 1979.

Mitchell, A.H.G., Geology of South Malekula, New Hebrides Condominium Geological Survey, 1966.

U.S. Bureau of Mines, Minerals Yearbook, U. S. Government Printing Office, Washington, D. C., 1977.

Warden, A.J., Genesis of the Forari Manganese Deposit, New Hebrides Institute of Mining and Metallurgical Transactions, Vol. 79, Sec. B, 1970.

APPENDIX A

ADAPTING USGS BULLETIN 1450A TO MANGANESE ASSESSMENTS

The Department of Interior in the preparation of Bulletin 1450A (recently superceded by USGS Circular 831) Principles of the Mineral Resources Classification System of the U. S. Bureau of Mines and U. S. Geological Survey introduces the subject of classification as follows:

GENERAL DEFINITION OF MINERAL AND ENERGY RESOURCES

The dictionary definition of resource "something in reserve or ready if needed" has been extended for mineral and energy resources to comprise all materials surmised to exist having present or future values. In geologic terms a mineral or energy resource is a concentration of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible. Material classified as a reserve is that portion of an identified resource producible at a profit at the time of classification.

Total Resources are materials that have present or future value and comprise identified or known materials plus those not yet identified, but which on the basis of geologic evidence are presumed to exist.

PHILOSOPHIC BASIS FOR A RESOURCE CLASSIFICATION

Public attention usually is focused on current economic availability of mineral or energy materials (reserves). Long-term public and commercial planning, however, must be based on the probability of geologic identification of resources in as yet undiscovered deposits and of technologic development of economic extraction processes for presently unworkable deposits. Thus, all the components of Total Resources must be continuously reassessed in the light of new geologic knowledge, of progress in science, and of shifts in economic and political conditions.

Another requirement of long-term planning is the weighing of total or multi-commodity resource availability against a particular need. To achieve this the general classification system must be uniformly applicable to all commodities so that data for alternate or substitute commodities can be compared.

To serve these planning purposes Total Resources are classified both in terms of economic feasibility and of the degree of geologic assurance.

General guides for the use of this classification system are as follows:

1. Resource categories and definitions in the classification, as specified in the glossary, should be applicable to all naturally occurring concentrations of metals, nonmetals, and fossil fuels. The categories may be subdivided for special purposes.

2. Definitions may be amplified, where necessary, to make them more precise and conformable with accepted usage for particular commodities or types of resource evaluations.

3. Quantities and qualities may be expressed in a variety of terms and units to suit different purposes, but must be clearly stated and defined.

This two-dimensional, conceptual base for classification established by the Bureau and the Survey is straightforward. It encompasses geologic uncertainty and economic feasibility, reflecting the simultaneous interaction of prices, costs, and technology. This generalized system, however, requires each type of mineral commodity to be adapted in a manner which accommodates the geologic, technical, and economic idiosyncracies of that commodity. In the absence of an established system for manganese resource assessment, the Panel on Manganese Supply and Its Industrial Implications of the National Research Council developed its own scheme for the purpose at hand.

In any resource classification system the key requirement is setting the criteria for determining among the Total Resources, how much can be considered reserves. This is the quantity of recoverable metal or mineral that is currently (time of estimation) producible under prevailing technology and economic conditions. Manganese reserves cannot be readily defined in terms of costs, prices, or by any simple mix of grade, tonnage, or depth criteria. Unlike many mineral commodities, manganese content alone offers a poor measure of what constitutes reserves. Producible, usable manganese depends upon what the users are prepared to accept in their various processes and are willing to charge into their furnaces. This varies according to country and location, and needs to reflect other constituents besides manganese in the material being used. Manganese is not customarily extracted, refined, and used in an elemental state. Rather it is added to the product being produced in a variety of chemical compounds and mixtures, accompanied by other elements and compounds. This provides considerable variation in what can be considered technically usable, and in the form of manganese that can be classified as a reserve.

Cost is always an important element in what constitutes a mineral reserve. However, of the various metallic elements that are combined to make steel, manganese contributes a rather small proportion of the final cost of finished steel. As a consequence, while relative delivered cost is important in the determination of what constitutes a workable manganese deposit, market price is not as directly usable as a means of establishing what constitutes manganese reserves as distinct from sub-economic resources as might be the case in some mineral commodities. It is important to recognize that a less accessible occurrence of manganese, despite the quality of the manganese bearing material contained therein may not be producible.

The classification of manganese resources must rest upon a deposit-by-deposit examination and decision as to what constitutes currently usable manganese-bearing material. This evaluation is a reflection of a proper combination of characteristics that are currently acceptable to the country or firms using or purchasing the manganese from each individual deposit. Thus, if a particular steel-producing nation is willing to produce and use manganese which might be considered sub-standard elsewhere, such occurrences of manganese currently constitute a part of the world's manganese reserves. However, local or regional practices can change and these deposits could revert to being classified as resources rather than reserves. Moreover, similar occurrences in other parts of the world where more stringent requirements prevail may have remained classified as sub-economic resources throughout.

In terms of geologic uncertainty, the degree of confidence and the required density of measurements to underpin this level of precision, was established for each type of manganese deposit under consideration. The requirement of a plus or minus 20 percent confidence factor is a fixed U.S.G.S. standard for measured. For indicated reserves the Manganese Panel adopted plus or minus 50 percent as the upper limit. Estimates of a lower quality of precision were placed in the inferred category. If, however, an occurence of manganese was deemed so poorly defined that the actual presence of a minable deposit was in question, then the estimates were placed in the hypothetical category as defined by Bulletin 1450A.

Much of the world's manganese has been evaluated using British terminology and practice or following the COMECON agreement made among the centrally-planned economies. In both cases, the accuracy, observational density, and other criteria are sufficiently well-publicized and reliable for the panel to convert data from one system to another. While this was not an exact process the similarities between systems are such that any error introduced was considered likely to be less than the original error of estimation.

Except for COMECON data, the panel adopted a grid density of at least one observation site per 125 square meters or less for the estimate to qualify as measured. If data points were greater than one per 500 square meters then the reserves were classified as inferred.

Reserves are customarily presented in terms of recoverable mineral or metal content. The panel used known recoverability factors wherever possible for this purpose, and estimated as necessary. For sub-marginal and hypothethical resources, in situ, data may be the only data available. However, the panel has been able to indicate manganese recoverability based on current practice for these categories also. This provides some insight into the quantities potentially available in the longer term. It should be noted that future changes in practice and economics could cause such recoverability factors to deviate over time.

Finally, the panel did not include marine resources and manganiferous iron ores in its examination of world data, so these currently or potentially usable sources of manganese are not included in the classification scheme or in the statistical table.

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